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An analysis of the Mexican electricity framework under the adoption of an emission trading scheme.

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Abstract

The Mexican power sector has started an ambitious transition since 2013 to open the sector to private investors. Constitutional amendments envisage a cleaner electricity sector, setting goals for renewable energy share in the electricity mix respectively 35% by 2024, 40% by 2035, and 50% by 2050. Simultaneously, Mexico has set targets to reduce GHG emissions including among others, the electricity sector. To achieve these goals, the Mexican government has recently announced the implementation of a mandatory Emission Trading Scheme (ETS). The study investigated the impact of adopting the ETS from 2017 to 2050 in the Mexican electricity sector.

The study used Open Source Energy Modeling System (OSeMOSYS) in order to build a model of the current Mexican electricity sector. Ten different scenarios were created to explore the evolution of the electricity industry in the country under an ETS (e.g. emissions limited and penalized). The conditional and unconditional Intended Nationally Determined Contributions (INDC) adopted by Mexico were considered to replicate the cap on emissions. The unconditional INDC implied 22% less emissions, whereas the conditional INDC suggested 50% less emissions. Furthermore, five different penalties on emissions were applied (2.5 USD/tCO2eq, 7.5 USD/tCO2eq, 15 USD/tCO2eq, 30 USD/tCO2eq, and 50 USD/tCO2eq).

The results suggest that when the ETS is not adopted the emissions continuously increase until 2050, and the renewable penetration targets are not achieved. Additionally, under a 22% less emissions cap the renewable penetration targets are not achieved in any scenario, however the GHG reduction target is attained in all the scenarios, both by 2031 and until 2050. Under a 50% less emissions cap, the GHG reduction targets are achieved; nonetheless, the renewable penetration targets are only achieved in 2024 and 2035, but not in 2050.

Finally, according to the simulations, the Mexican electricity sector showed a high level of dependency on conventional technologies fueled by natural gas (i.e. combined cycle and gas turbine power plants) by 2050. Solar PV had the largest power generation share, followed by onshore wind power. Only under a 50% less emissions cap, offshore wind power penetrated the Mexican electricity sector.

Keywords Mexico, Emission Trading Scheme (ETS), OSeMOSYS, INDC

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Contents

Abbreviations

BAU	Business-as-Usual
CCC	Council on Climate Change
CEL	Clean Energy Certificates
CENACE	National Energy Control Center
CFE	Federal Electricity Comission
CICC	Intergovernmental Commission on Climate Change
COP	Conference of the Parties
CRE	Agency of Energy Regulation
ETL	Energy Transition Law
ETS	Emission Trading Scheme
FTR	Financial Transmission Rights
GHG	Greenhouse Gases
IEA	International Energy Agency
INDC	Intended Nationally Determined Contribution
INECC	National Institute of Ecology and Climate Change
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
KTH	Royal Institute of Technology
LAERFTE	Law on Renewable Energy Utilization and Energy Transition Financing
LGCC	General Law on Climate Change
LIE	Electric Law Industry
MEM	Mexican Wholesale Electricity Market
NPV	Net Present Value
OSeMOSYS	Open Source Energy Modelling System
PEMEX	Mexican Petroleum
PIIRCE	Indicative Program for the installation and retirement of Electric Generation Facilities
PRODESEN	National Electric System Development Program
RES	Reference Energy System
RGD	National Distribution Network
RNE	GHG Register Regulation
RNT	National Transmission Network
SEMARNAT	Secretariat of Environment and Natural Resources
SENER	Ministry of Energy
SNCC	National System for Climate Change
UNFCCC	United Nations Framework Convention on Climate Change

List of Units

J	[kg * m^2 /s^2]	Joules
W	[J /s]	Watt
kWh	[W*hour]	kilowatt*hour (10^3 Watt*hour)
tCO_2	[Metric Ton]	Concentration of CO_2
tCO_2 eq		Concentration of Greenhouse Gases based on their global warming potential
kW	[J/s]	kilowatts (10^3 Watt)
GJ	[kg * m^2 /s^2]	Gigajoules (10^9 Joules)
GW	[J /s]	Gigawatts(10^9 Watt)
MJ	[kg * m^2 /s^2]	Megajoules(10^6 Joules)
MW	[J/s]	Megawatts(10^6 Watt)
TWh	[W*hour]	Terawatt*hour (10^9 Watt*hour)

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1 Introduction

1.1 Motivation

Global warming is one of the greatest challenges that human kind will face during the 21st. century. The urgency to reduce and limit emissions relies on the fact that there is scientific evidence which has demonstrated how human activity has influenced climate change. The main reason to sustain this argument is because of the proven increase of GHG concentration in the atmosphere and the rise in temperatures around the globe (Gao, Huang, Chen, Chen, & Liu, 2018). According to different researchers, global warming would cause in the future extreme climatic events such as variability of precipitation patterns, changes of tropical storm activity, accelerated sea-level rise, among other consequences (Azuz-Adeath & Yañez-Arancibiab, 2018), jeopardizing food security and infrastructure in cities and coastal regions across the planet (CEPAL, 2004). In fact, economic and social impacts are projected to occur at a global scale in the upcoming years (Azuz-Adeath & Yañez-Arancibiab, 2018).

Nevertheless, in 1992 representatives from countries from all over the world were gathered during the first United Nations Framework Convention on Climate Change Convention (UNFCCC), and agreed to sign an international cooperation treaty to cope with the threat that global warming represents for humanity (UNFCCC, 2016). This was the first commitment that was made globally to anticipate, prevent and minimize the effects of climate change (CEPAL, 2004). Furthermore, many countries have agreed in 2015, during the COP21, to limit the emission of greenhouse gases (GHG) to maintain the increase of the global surface temperature of the earth into an average range of 2°C above pre-industrial levels (Cruz-Cano, Elizondo, Pérez-Cirera, Strapasson, & Fernández, 2017). For this reason, several Latin-American countries are committed to addressing global warming and climate change by implementing strategies to achieve GHG reduction goals (Toumi, Le Gallo, & Ben Rejeb, 2017). Among those, Mexico is under international pressure to take actions to fight climate change as it plays an important role in the region (Octaviano, Paltsev, & Costa Gurgel, 2016). For this reason, Mexico signed the Kyoto Protocol on 9th June 1998, and ratified it on 7th September 2000 (UNFCCC, 2016). Furthermore, the country has also adhered the Paris Agreement on 4th November 2016 (UNFCCC, 2016). As a result, the country is committed to reduce its emissions according to its Nationally Intended Contributions (NDC) subscribed under the treaty (Federal Government of Mexico, 2018). Under those circumstances, the Mexican government has started the transition to a cleaner electricity sector, by laying the foundation" in the legal and political arenas" (Ortega Díaz & Casamadrid Gutiérrez, 2018).

Consequently, the Mexican authorities launched the national climate policy stating that GHG emissions should decrease 30% by 2020, and 50% by 2050, compared to the levels in 2000 (SEGOB, 2016). Furthermore, the Federal government has also established targets to be achieved in clean electricity generation. The Law for Energy Transition and Renewable Energies (LAERFTE) states that, by 2024, no more than 65 % of the electricity will be produced from fossil fuels (Chamber of Deputies, 2013).

The General Law on Climate Change (LGCC) from 2012 contemplated the promotion of cost-effective measures to attain reduction on GHG emissions (LGCC, 2018). Under these circumstances, on 12th December 2017, the Mexican Parliament announced the adoption and implementation of an Emission Trading System (ETS) in the country (ICAP, 2018) (Federal

Government of Mexico, 2018). Essentially, under this scheme, the emissions of GHG will be limited and they must be kept below a cap. Emissions permits or allowances will be traded in a regulated market among those entities with obligation to reduce emissions (ICAP, 2018).

1.2 Objective

The present study aims to explore how the adoption of a mandatory Emission Trading Scheme would influence the achievement of the renewable penetration targets set by the Mexican government by 2024, 2035 and 2050. This is done using the Mexican electricity system modeled in the Open Source energy MOdelling SYStems (OSeMOSYS). OSeMOSYS was chosen as a modeling tool because it is a free software license optimization tool, so it does not require upfront investments. Furthermore, the learning curve to build a model and operate the tool is lower when compared to other similar modeling tools (OSeMOSYS, 2018). Moreover, It has been previously used, among other studies, to analyze the national energy systems in Cyprus (Taliotis, Rogner, Ressl, Howells, & Gardumi, 2017), and Tunisia (Dhakouani, Gardumi, Znouda, Bouden, & Howells, 2017). It has also been used to evaluate the impact of implementing environmental policies on the energy systems at a regional or national level (Lyseng, Rowe, Wild, English, Niet, & Pitt, 2016) (English, et al., 2017). This study presents the first deployment of the tool for Mexican case.

The key research questions being asked are:

How will the adoption of a Cap and Trade System affect the achievement of the targets set for renewable penetration in the country?

What is the most cost-effective policy mix (emission limit - emission penalty) to leverage the Mexican electricity sector into a more sustainable future?

The report is organized as follows: In the first place, chapter 2 introduces the methodology and presents the Open Source Energy Modeling System (OSeMOSYS). The chapter 3 contextualizes the Energy and climate policy frameworks in Mexico, as well as the international Agreements subscribed by the country to reduce its levels of GHG emissions. Next, chapter 4 describes the existing infrastructure of the Mexican Electric Power System for electricity generation, transmission and distribution, as well as the renewable energy potential in the country. Subsequently, in the chapter 5 the modeling process and the different scenarios are explicated. Then the validation process of the BAU model is presented in the chapter 6. The results of the simulations for all the scenarios are reported in the chapter 7, and finally the conclusions are extended in the chapter 8.

2 Methodology

The research started with a vast bibliographical review to understand and to describe the current status of the Mexican electricity sector, including the power generation infrastructure, the legal framework that regulates the industry and the statutes for renewable energy penetration and emissions regulation. In addition, the international agreements ratified by the Mexican authorities were briefly studied to understand the commitments acquired.

Secondly, based on the information gathered after the bibliographical review on the infrastructure of the Mexican power sector, the Reference Energy System (RES) was developed. The RES was an effective graphical description of the Mexican electricity system that provided a good understanding of the fuels used and the conversion technologies employed to generate electricity. After RES development, the process continued with the data mining stage which consisted in gathering technical and economic information of the different technologies used to generate electricity in Mexico. Subsequently, the modeling process in OSeMOSYS started and all the previous data gathered were utilized to build the Business-as-Usual (BAU) scenario. OSeMOSYS as a modeling tool will be presented in the section 2.1. Eventually the BAU was validated by correlating the results obtained in the simulation with the information published in the National Electric System Development Program (PRODESEN), for both installed capacity and electricity generation. Once the BAU was verified, it was used to simulate several scenarios by exploring the performance of the electric system by limiting the emissions of CO_2eq, and by applying different penalties on emissions. Finally, the results of the simulations were analyzed and the conclusions were determined. The conclusions were drawn considering the achievement of renewable targets and the abatement costs incurred in each scenario.

Figure 1 summarizes the methodology followed during the modeling process to develop the BAU and the other scenarios required to assess the impact of an ETS in the Mexican Electricity Sector.

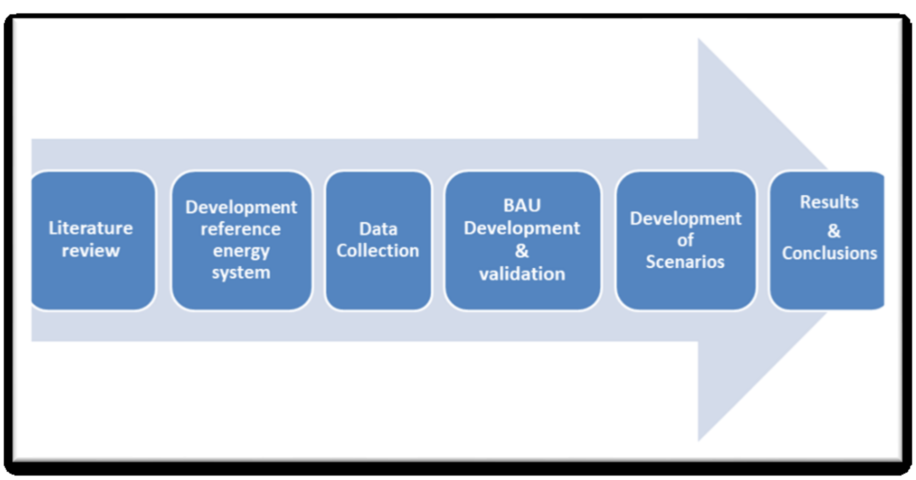


Figure 1.Methodology

2.1 Modeling tool

The Open Source energy Modeling System (OSeMOSYS) was selected as a modeling tool to develop the scenarios because it is an open source for energy systems modeling linear optimization program for long-range analysis (Beltramo, et al., 2018). Additionally, it is a software application developed by different renowned international organizations such as the Royal Institute of Technology (KTH) in Sweden in collaboration with other institutions, and unlike other modeling tools, OSeMOSYS does not require any upfront investment or the purchasing of any software license. Furthermore, the code can be consulted online, and the interface and the solver can be downloaded from the internet (OSeMOSYS, 2018).

Equally important, OSeMOSYS has been previously used as modeling tool in different study cases to analyze the interaction between environmental policies and their impact on the power sector. In 2017, Taliotis et al. used OSeMOSYS to explore different scenarios for the future electricity system in Cyprus. The research was focused on analyzing the transition towards a power generation industry more dependent on natural gas, due to the available offshore gas reserves recently discovered in the exclusive economic zone of the island. Moreover, the projections were made considering the EU climate and energy policies, including the renewable generation targets established to be achieved by 2020. The authors also considered the own renewable penetration goals determined by the local government in the National Renewable Energy Action Plan. The conclusions of the investigation suggested that supply of natural gas for electricity generation was expected to be irregular during the model period, and the utilization and investment in renewables sources should be considered by the Cypriot authorities (Taliotis, Rogner, Ressl, Howells, & Gardumi, 2017). Moreover, in their research work, Lyseng et al. explored the effect of implementing a carbon pricing in the electricity sector in the province of Alberta, in Canada. To assess the impact of applying the carbon pricing as a policy, 13 different scenarios were developed. All the conditions were maintained in all the scenarios. Only the carbon price rate, the natural gas price and the costs for wind and solar technologies were adjusted in order to understand the behavior of the electricity system under different conditions. The researchers conclude that by implementing a policy such as a carbon pricing, the electricity sector in Alberta shifts to a less carbon intensive sector by 2060. Additionally, the investigators found that the most cost-effective transition involved more autonomy from coal, but the reliance on natural gas increased (Lyseng, Rowe, Wild, English, Niet, & Pitt, 2016).

Furthermore, English et al. investigated the least expensive scenario for a future expansion in electricity transmission capacity between the Canadian provinces of Alberta and British Columbia. In their research, the energy system from both provinces were developed using OSeMOSYS as the assessment tool. Moreover, to conduct the study the analysts not only considered GHG reduction goals in the electricity sector, but also contemplated renewable generation targets set by the authorities. The results showed that when carbon policies were implemented, the interconnection capacity reduces the costs of the electricity. In addition, the penetration of renewables was not affected by the adoption of carbon pricing policies (English, et al., 2017).

3 Background

3.1 Mexican Energy and Climate policy Framework

The first efforts made by the Mexican authorities to protect the environment started in 1971 when the Federal Law to Prevent and Control environmental Pollution was published. Later on, it served as the foundation for what has been known as the General Law on Ecological Balance and Environmental Protection, promulgated in 1988 (Yamin Vázquez, 2013). This new legislation stated for the first time the establishment and implementation of programmes to reduce emissions, including measurement tools and the establishment of inventories of emissions (Graham Research Institute, 2014). In the meantime, several debates concerning the environment and the climate were raised internationally (i.e. UNFCCC). Eventually, those discussions not only influenced the environmental awareness in Mexico, but also the policies promulgated in the upcoming years.

3.2 Mexico and the UNFCCC

In 1990, the United Nations General Assembly convoked the Intergovernmental Negotiation Committee (INC) for a Framework Convention on Climate Change (UNFCCC). After two years of negotiations, on 9th May 1992 the text for the UN Framework Convention on Climate Change was published. The document envisaged actions to be taken to stabilize the concentration of GHG in the atmosphere, and to keep the emissions under proper levels so they could not interfere with the climate (UNFCCC, 2016).

In June 1992 the United Nations Framework Convention on Climate Change (UNFCCC) took place in Rio de Janeiro, Brazil. During the Earth Summit in Rio, two main topics were treated: the contention of GHG emission (Toumi, Le Gallo, & Ben Rejeb, 2017) and the adaptation caused by climate change (Government of Canada, 1992). During the session, an agreement was signed by more than 130 nations, also known as parties (Government of Canada, 1992). Mexico was among the signing parties of the UNFCCC in 1992, and the same year the Mexican Congress unanimously approved the commitments acquired (i.e. reduction of GHG emissions) (INECC, 2018).

Two years later, on 21st March 1994 the UNFCCC entered into force with 196 members signing the treaty. Ever since this first meeting, parties have an annual meeting to discuss the achievements reached, but also to "negotiate multilateral responses to climate change". The annual meetings are called the Conference of the Parties (COP) (CEPAL, 2004).

3.3 The Kyoto Protocol

On December 11th 1997, the COP3 was held in Kyoto, Japan. The encounter resulted in a "historical milestone" (Toumi, Le Gallo, & Ben Rejeb, 2017). It was the first time an agreement was established to reduce the emission of GHG and to address climate change, the so-called Kyoto Protocol (Toumi, Le Gallo, & Ben Rejeb, 2017). The Kyoto Protocol can be considered as a turning point to a "carbon market economy" (CEPAL, 2004).

The protocol set the guidance to be followed by the signing parties to fulfill their commitments to reduce their GHG emissions and to comply with the obligations acquired. The protocol recognized the responsibility of developed countries and the role they have played during more than 150 years of industrial activity causing the current high levels of GHG emissions. Furthermore, it was designed under the principle of "Common but differentiated responsibilities". Countries with specific commitments were listed in the "Appendix I", and non-Appendix list was formed by "the rest of the world including the so-called developing South" (Corbera & Jover, 2014). Mexico signed the Protocol on June 9th 1998, and the Congress approved the ratification on 29th April 2000 (INECC, 2018).

According to the guidelines, the reduction targets under the Protocol can be attained "in the most cost-effective" way either through national environmental measures or policies, i.e. by investing in more efficient technologies with less GHG emissions, or through additional instruments, also known as "flexible mechanisms" (Endres & Ohl, 2005). For instance, under the protocol two project-based investment mechanisms were introduced: clean development mechanism (CDM) and joint implementation (JI); and one market-based investment mechanism: emissions trading (UNFCCC, 2016).

CDM had two implicit purposes. The first was to promote emission reduction projects in developing countries. The latter received CER's (certified reduction credits) which could be used to assist developed countries to achieve their own GHG reduction goals (Benites-Lazaro, Gremaud, & Benites, 2018). In addition, by investing in developing countries, CDM projects were expected to generate not only "environmental benefits", but also "socioeconomic opportunities" in less developed countries (Corbera & Jover, 2014). JI projects work similarly but the difference relies in the fact that JI projects were executed by two developed countries committed to reduce their GHG. The country that develops or finances the project accredits emission reduction (BMU, 2018).

On the other hand, under an emission trading scheme a mandatory limit on GHG emissions is set. Then, obligated participants, either countries or companies, must achieve mandatory GHG reductions by selling or buying carbon permits, also known as tradable allowances. In January 2005, the European Trading system was launched. It is considered the world's largest cap and trade scheme ever implemented in the world (Department of Energy & Climate Change, 2015) and most important pillar of environmental policies focused on reducing GHG (UNFCCC, 2016) In section 3.5.3 a more detailed explanation about the working principle of a cap and trade system can be found.

3.4 Mexico and the Paris Agreement: Setting Emissions Reductions Targets

In December 2015, during the COP21 in Paris, the international community set ambitious goals in the global climate agenda. The first was to limit the global temperature rise below 2° C. The second one was even more ambitious. It demanded the commitment of the parties to keep the temperature even further to 1.5° C above the pre-industrial levels (Fragkos, Tasios, Paroussos, Capros, & Tsani, 2017). The temperature should be kept below the limits through a regime of "reduction targets for all signatories" (Azemraw Senshaw & Won Kim, 2018).

During the Conference, the parties were invited to present their own national efforts to reduce their national emissions (Balibar, 2017). These are also known as Intended Nationally Determined Contributions (INDCs). The INDC set specific targets to be achieved by 2030, and "instruments with legal force under the UNFCCC negotiations" (Balibar, 2017).

On 27th of March 2015, the Mexican authorities updated the contributions of the country to be presented in Paris. The unconditional target to be achieved was set at 22 % less GHG emissions by 2030. The objective implies a total reduction of 762 $MtCO_2eq$ by 2030 (Table 1). Furthermore, by accepting the unconditional reduction target, a pathway to achieve 50% less emissions by 2050 was set, and approved by the Mexican authorities (Mexican Federal Government, 2014). The sectors obligated to reduce their emissions are: transport, electricity generation, residential and commercial, industry, waste, and agriculture and livestock (Mexican Federal Government, 2014). Table 1 shows the GHG reduction goals established for each sector in the column GHG Target 2030 (MtCO2eq). The targets to be achieved in 2030 were set according to the projections obtained from a baseline scenario by 2020, 2025 and 2030. The targets were set according to the projections calculated by the Mexican authorities.

Table 1. GHG Reduction Unconditional Goals (Mexican Federal Government, 2014)

Sector	GHG emissions (official projection)				GHG Target 2030($MtCO_2e$)
	2013	2020	2025	2030	
Transport	174	214	237	266	218
Electricity Generation	127	143	181	202	139
Residential & commercial	26	27	27	28	23
Oil and gas	80	123	132	137	118
Industry	115	125	144	165	157
Agriculture and livestock	80	88	90	93	86
Waste	31	40	45	49	35
LULUCF	32	32	32	32	-14
Total Emissions	**665**	**792**	**888**	**973**	**762**

Eventually, the Mexican authorities subscribed and ratified the Paris agreement on 22nd of April 2016. And on September 14th 2016 the Congress of Deputies approved it (INECC, 2018). The ratification of the Paris Agreement came into effect on 4th of November 2016, converting INDC as mandatory contributions for those signing parties (Azemraw & Won, 2018).

3.5 Mexican Energy policy Framework: Breaking Paradigms

In order to achieve the GHG emission targets and to comply with the international commitments, the transformation of the Mexican electricity industry through a structural reconfiguration was crucial. The transition into a modern arrangement started in 2013 with the Energy Reform. Since the earlies 1930's, the Energy sector in Mexico was constituted by state-owned companies that practically monopolized the activities in both oil & gas and power generation sectors. Petróleos Mexicanos (PEMEX) controlled the oil and gas value chain for upstream, midstream and downstream activities (IEA, 2016). On the other hand, since its creation in 1937, Comisión Federal de Electricidad (CFE) controlled the power generation industry, including the transmission and distribution activities, but also the retail sales. Figure 2 shows the former structure of the electricity sector, when only CFE had the jurisdiction to control the operation of the electric sector (Alipzar-Castro & Carlos, 2016).

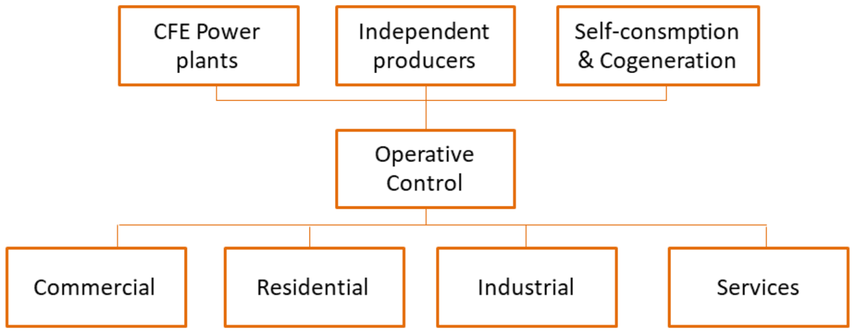


Figure 2. Former structure of the Mexican Electricity Sector (Alipzar-Castro & Carlos, 2016)

The participation of private generators was limited only to self-consumption, export & import of electricity or direct sale to CFE (KPMG, 2016). Private generators interested in providing electricity to the grid, were obligated to sign interconnection agreements with CFE, which increased the costs of electricity. Additionally, the expansion of the grid was also under the control of the stated-owned company (Alipzar-Castro & Carlos, 2016). The monopoly had a considerable impact on electricity prices, as they were regulated and subsidized by the government. According to Hernández Alva, in 2013, the average tariff of the electricity was 25% higher than the average tariffs in the USA. Without subsidies, the difference was 73% higher in Mexico (Hernandez Alva, 2016).

3.6 The Energy Reform

In 2013, the Mexican constitution suffered one of the most important modifications regarding the oil & gas and power sectors. The new regulations ended an era of 75 years of limited private investments in the energy sector that began in 1938 after the Industry nationalization carried out by former Mexican president Lázaro Cárdenas (Rosales, 2017). As previously discussed, during this period, the regulation framework of the industry was highly restrictive to the participation of private investors in the oil & gas and electricity sectors (Alipzar-Castro & Carlos, 2016). The Reform sought the transition to a more competitive and efficient energy sector (Graham Research Institute, 2016). The Energy Reform was nourished with a series of specific regulations and decrees which aim to invigorate the changes required not only to transform the electricity sector, but also to encourage the achievement of the environmental commitments acquired internationally to reduce the emission of GHG.

3.7 Electricity Industry Law (LIE)

Published on August 11th, 2014 the LIE sets the foundations for a new electric industry in Mexico, allowing private companies to compete and participate in the process of generation, transmission and distribution, as well as supply activities. These activities are now legally separated, setting the foundations of a new competitive market. The objective is to have electricity at lower prices (Alipzar-Castro & Carlos, 2016).

The industry will be managed by three different bodies. The Ministry of Energy (SENER) is in charge of the policy governance and the management of upstream activities. The Agency of Energy Regulation (CRE) will regulate the operation of the industry, and the National Center of Energy Control (CENACE) will administrate the power grid and the sale market, including the monitoring of the electricity prices (SENER, 2017) (CMS, 2017).

The LIE also settled the foundations of the Mexican Wholesale Electricity Market (MEM). The MEM entered into operation in January 2016, and for the first time in history, electricity was commercialized between consumers and private generators (Zenón & Rosellón, 2017). The operation of the market will be ruled by the forces of the supply and demand of electricity.

In the new configuration of the market, the generators can be either private companies or independent subsidiaries of CFE. As the market has been now liberalized to free competition, all the generators compete to produce and sell electricity. It can be directly sold into the system through CENACE, or can be sold to another participant or user in the market. Each power generator is free to set the price for the electricity they generate. However, they have to report every day their operation costs to the CENACE (CMS, 2017).

Furthermore, different products can be traded among the users, not only electricity. The other products that can be traded are: Power (e.g. companies are obligated to destine their installed capacity to generate electricity whenever is required), financial transmission Rights (FTR) and Ancillary Services and Clean Energy Certificates (CELs). The LIE introduced CELs as financial instruments to promote investments in green technologies and to achieve the targets adopted for clean energy generation. Each generator that produces electricity from clean sources can obtain one CEL per 1 MWh of electricity generated. According to the rules stipulated by SENER, suppliers and users imposed to consume certain percentage of clean energy are obliged to buy as many CELs required fulfilling their obligations (CRE, 2016). According to the Ministry of Energy, 14.7 million of CELs has been issued to cover a portion of the obligations for the period 2018-2019. The number of CEL assigned will cover 39% of the obligations in 2018 and 56% in 2019 (PRODESEN, 2017) (SENER, 2017).

3.8 General Law on Climate Change

On January 6th 2012, the Mexican government announced the General Law on Climate Change (LGCC). By approving this Law, the local authorities put Mexico in the innovative pathway to move forward towards a low carbon economy (Graham Research Institute, 2016). As it was the first developing country to decree a law against climate change (Ortega Díaz & Casamadrid Gutiérrez, 2018).

In this legislation, ambitious voluntary goals have been set. Among those goals, a reduction target of 20% below GHG emission levels in 2000 (baseline) by 2020 is contemplated. In addition, the law sets an even more ambitious target to be attained by 2050, when GHG emission reduction should be 50% lower than the baseline (LGCC, 2018). The targets to reduce GHG emissions stated in the LGCC were then coupled with the targets acquired after the ratification of the Paris Agreements. To achieve the goals, the institutional framework is being strengthened to support and promote the participation of critical stakeholders. New governmental bodies have been either improved or created in order to coordinate the transition across different sectors from the government, civil society and academia. The Intergovernmental Commission on Climate Change (CICC), the Council on Climate Change (CCC), the National Institute of Ecology and Climate Change (INECC), the National System for Climate Change (SNCC) are the governmental bodies dedicated to coordinate the regulations, policies and strategies required to make a more resilient country against climate change (IDLO, 2013).

Additionally, the LGCC contemplates the implementation of the GHG inventory according to the methodology followed by the United Nations. Consequently, it is has been projected the creation of a GHG register regulation (RNE), to certify the accurate measure, report and verification of the emissions of GHG (Graham Research Institute, 2016). The law also specified which GHG are subjected to be reported. The list includes all the GHG covered under the Kyoto Protocol (e.g. carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride) (UNFCCC, 2016), but the Mexican legislation adjoined to the list the black carbon or soot (SEMARNAT, 2014).

Conventionally, efforts to reduce GHG emissions were made through command-and-control regulations. Under command-and-control policies, explicit directives to reduce emissions are imposed with relatively little flexibility, which means that regulated bodies are forced to assume "similar shares of pollution-control burden regardless the cost" (Stavins, 2001). Nonetheless, LGCC introduced two market-based instruments as a new approach to regulate pollution: the cap and trade system and carbon tax. The objective of these market-based environmental policies is to "equalize the marginal costs that firms spend to reduce pollution", and also to allocate the pollution in a more cost-effective way among the emitters (Stavins, 2001).

Emission trading scheme

The emission trading scheme is one of the market-based policies to be implemented in Mexico after the amendments of the law. Initially, the LGCC established the basic framework for the adoption of a voluntary emission trading scheme. However, on December 12th 2017, the law was revised, and the implementation of an emission trading scheme became obligatory (SEMARNAT, 2018). Under the cap and trade system, the authorities will impose a mandatory limit on emissions, or a cap. Furthermore, the government will determine the individual emitters forced to reduce their emissions. The cap will be composed of permits, also known as allowances, which accredit the holder the right to emit certain amount of pollutants (EPA, 2017). To comply with the regulations obligated individuals must hold the number of allowances required to cover the amount of pollution they produce. Firms can either sell or buy allowances to achieve the reduction goal under a regulated market (Government of Canada, 2018). If the obligated entity does not comply with the reduction target, a sanction can be imposed according to the specifications established in the law (UN, 2017). Next figure 3, exemplifies the working principle of an ETS.

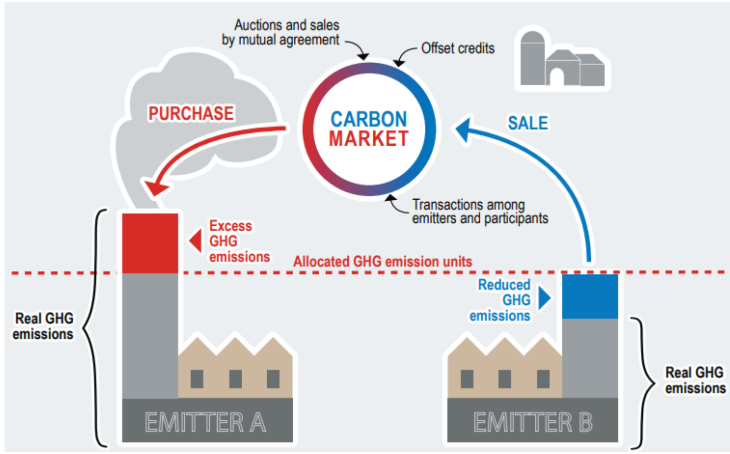


Figure 3. Exemplification of a Cap and trade scheme (Government of Canada, 2018)

With this arrangement, each regulated individual has the flexibility to follow its own abatement path and to attain its own reduction target in the most "cost-effective way" (Nicholas Institute for Environmental Policy Solutions, 2018).

Carbon Tax

The LGCC also considered a tax on fossil fuels (Table 2) as part of the fiscal instruments required to achieve the targets set to reduce emissions (IETA, 2018). The tax rate is imposed based on the content of CO_2 of the fossil fuel. Nonetheless, and according to the authorities it was introduced to internalize a proportion of the externalities caused by the consumption of fossil fuels (SEMARNAT, 2017). One characteristic is that the tax rate is not fixed, and it is adjusted every year according to the inflation. However, the law also stipulated that the tax rate should be lower than 3% of the sales price of the fuel (IETA, 2018) (SEMARNAT, 2016).

Table 2. Tax on fossil fuels (in Mexican pesos) (SEMARNAT, 2016)

Fuel Oil	Quota	Units
Propane	6.5	¢/l
Butane	8.42	¢/l
Natural Gas	11.41	¢/l
Jet fuel	-	¢/l
Turbosine	13.64	¢/l
Diesel	13.84	¢/l
Fuel Oil	14.78	¢/l
Oil Coke	17.15	MXN/ton
Mineral carbon	30.28	MXN/ton
Coal Coke	40.21	MXN/ton

3.9 Energy Transition Law (ETL)

On December 10th, 2015 the Mexican Congress approved the Energy Transition Law (ETL) (Ernst & Young , 2015). Among other questions, it set ambitious goals for clean energy share in the electric sector. According to the ETL, by 2021, the share of renewables should attain 30 % of the electricity production in the country. Additionally, the electricity generated from renewables should account by 35 % by 2024, and 50% by 2050 (Graham Research Institute, 2016). In addition, the ETL also established goals to be achieved in terms of energy efficiency. According to the document, between 2016 and 2030 the energy intensity in the country should be reduced by 1.9%. Furthermore, for the period between 2031 and 2050, energy efficiency should achieve a reduction of 3.7% (Federal Government of Mexico, 2016).The reform also promotes the sustainable use of fuels with lower emissions of GHG (Graham Research Institute, 2016).

4 Installed capacity and electricity generation

4.1 Current Installed Capacity

Different technologies are used to generate electricity in Mexico. The information about the installed capacity can be found in the National Electric System Development Program (PRODESEN) published by the Federal Government which contains the infrastructure development scheme of the electric system. The current infrastructure to generate electricity consists of conventional technologies and clean technologies. The conventional technologies are those that are powered by fossil fuels, emitting GHG into the atmosphere when the fuel is burnt during the combustion process. The generation of electricity contributes to 19% of the total GHG emissions in Mexico (PRODESEN, 2017).

The existing infrastructure of conventional power plants is composed by 71 combined cycle power plants, 60 Conventional thermal power plants, 3 coal power plants, 2 fluidized bed power plants, 128 gas power plants and 253 internal combustion power plants (PRODESEN, 2017). Furthermore, the installed capacity includes 84 hydropower plants, 1 nuclear power plant, 41 wind power plants, 8 geothermal power plants, 17 photovoltaic power plants and 75 bioenergy power plants. Table 3 shows the total the Total Installed Capacity in 2015 and 2016, as well as the annual growth rate.

In 2016, the installed capacity (Table 3) reached 73,510 MW in 2016. It rose 7.2% compared to the capacity in 2015. A total capacity of 52,339 MW from conventional technologies was installed in 2016 (SENER, 2017).

Table 3. Installed Capacity Installed Capacity in 2016 (PRODESEN, 2017)

Technology	2015 (MW)	2016 (MW)	Annual growth rate
Combined Cycle	24,043	27,274	13.44%
Thermal power plants	12,711	12,594	-0.92%
Coal power plants	5,378	5,378	0.00%
Gas power plants	4,904	5,052	3.02%
Internal Combustion	1,186	1,453	22.51%
Fluidized bed power plant	580	580	-
Hydro	12,489	12,589	0.80%
Wind	2,805	3,735	33.16%
Geothermal	884	909	2.83%
Solar	56	145	158.93%
Bioenergy	760	889	16.97%
Distributed Generation	118	248	110.17%
Nuclear	1,510	1,608	6.49%
Efficient Cogeneration	583	1,036	77.70%
Regenerative braking	7	7	-
Others	13	14	7.69%
TOTAL	**68,025**	**73,510**	**8.06%**

From 2015 to 2016, the share of renewables rose 10.2%, with new capacity from wind power plants (930 MW), and efficient cogeneration technologies (453 MW) (PRODESEN, 2017). Figure 4 shows the share of Installed Capacity by technology in 2016.

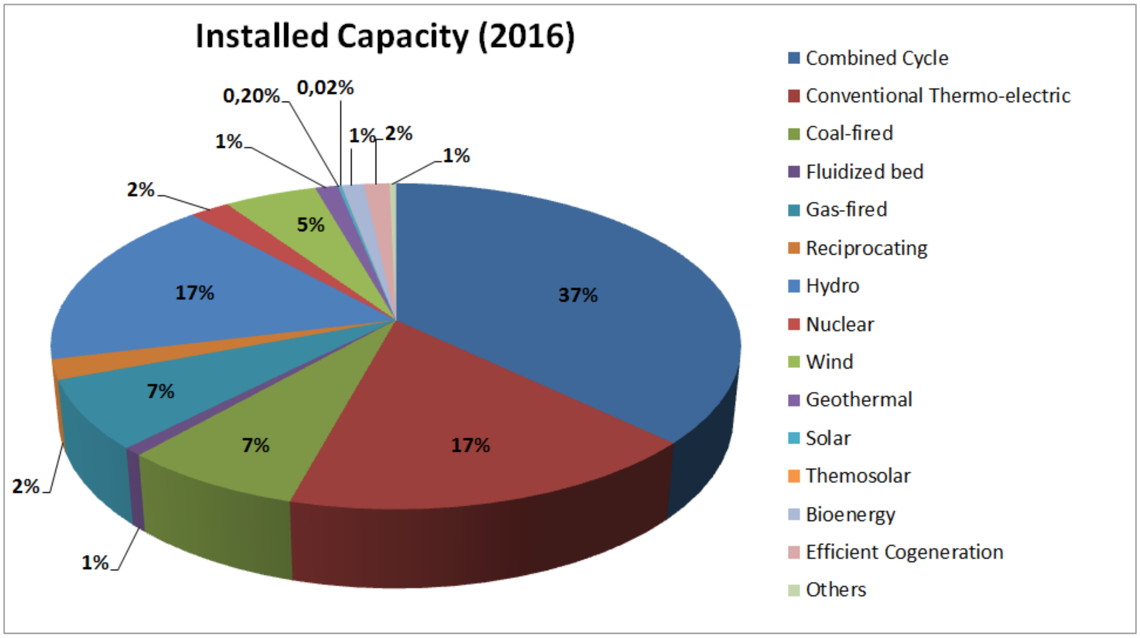


Figure 4. Share of installed capacity by technology (PRODESEN, 2017)

4.2 Future Installed Capacity

During the upcoming years more changes will modify the infrastructure in the country. The government has plans to cancel capacity from conventional thermoelectric and gas-fired power plants as established in the Indicative Program for the installation and retirement of Electric Generation Facilities (PIIRCE). PIIRCE projects the power demand, and adjusts the capacity to meet both the electricity and the targets on renewable generation (PRODESEN, 2017).

According to the projections, the installed capacity of conventional thermoelectric power plants will decrease from 12,172 MW in 2017, to 2,097 MW in 2031. Equally, 1,271 MW of capacity from coal-fired power plants will be phased-out. On the other hand, the share of installed capacity of solar power will increase in 2018, when capacity will rise 377%, compared to 2017. The trend will continue in 2019 (58% more than previous year), 2020 (28%). After 2020, the projections show a stable diffusion (PRODESEN, 2017). The construction of wind power plants presents a similar trend, with important volumes of penetration in 2018 (24%), 2019 (24%) and 2020 (14%). After 2021, the trend of new capacity shows a steady tendency, between 5% to 10% of added infrastructure. Moreover, geothermal power generation will be enhanced from 2022 onwards. However, the highest rate of new capacity will be reached in 2024 with 11% more capacity than in 2023. Then the capacity will increase by 9% in 2025, by 11% in 2026 and by 17% in 2027. The increase percentages are relative to the previous year (PRODESEN, 2017).

4.3 Generation by source

In 2016, 319,364 GWh of electricity were supplied in the country. 254,296 GWh (79.7%) were generated by conventional technologies, whereas 64,868 GWh (20.3%) were generated by clean technologies (SENER, 2017). Table 4 shows the generation annual growth rate from 2015 to 2016 (PRODESEN, 2017).

Table 4. Total Generation by technology in 2015 & 2016 (SENER, 2017)

Technology	2015 (GWh)	2016 (GWh)	Annual growth rate
Combined Cycle	155,185	160,378	3.35%
Thermal power plants	39,232	40,343	2.83%
Coal power plants	33,599	34,208	1.81%
Gas power plants	11,648	12,600	8.17%
Internal Combustion	2,651	3,140	18.45%
Fluidized bed power plant	4,286	3,826	-10.73%
Hydro	30,892	30,909	0.06%
Wind	8,745	10,463	19.65%
Geothermal	6,331	6,148	-2.89%
Solar	78	160	105.13%
Bioenergy	1,369	1,471	7.45%
Distributed Generation	128	56	-56.25%
Nuclear	11,577	10,567	-8.72%
Efficient Cogeneration	3,795	5,053	33.15%
Regenerative braking	4	4	-
Others	33	36	9.45%
TOTAL	**309,553**	**319,364**	**3.17%**

4.4 Transmission & Distribution

The national transmission network (RNT) is grouped into 53 regions (Figure 5). 45 regions are interconnected, whereas 8 are independent regions located in the Baja California Peninsula. In 2016, the transmission capacity reached 72,450 MW in the interconnected regions, and 1,758 MW in the independent regions. The infrastructure of transmission lines attained 51,538 km. Finally, the distribution network (RGD) reached a total length of 831,087 km.

Furthermore, the transmission and distribution infrastructure includes 13 international interconnections with the Southern part of the United States in northern Mexico, and with Guatemala and Belize in the southern part of the country (Figure 6) (PRODESEN, 2017).

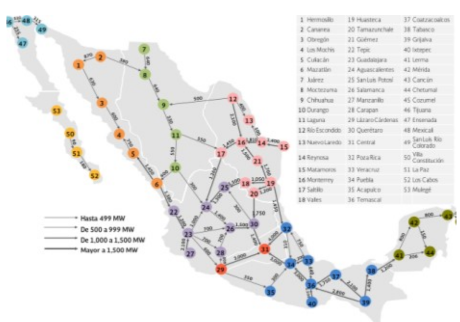


Figure 5. Mexican transmission network (PRODESEN, 2017)

Figure 6. International Interconnections (PRODESEN, 2017)

4.5 Renewable Energy Potential

For a proper development of the future Mexican energy system under an ETS, it is necessary to know the renewable energy potential that the country possesses. According to the National Projection, Mexico has proven resources of 12,000 MW of wind power, 1,932 MW of geothermal resources, 8,763 MW of hydropower and 8,000 MW of solar PV installations (PRODESEN, 2017). Additionally, the Ministry of Energy has stated in the Renewable Energy Prospective (2017-2031) that Mexico has the proven potential to generate 2,610 GWh/year from geothermal sources, 4,920 GWh/year from hydropower plants, and 3,326 GWh/year from biomass (SENER, 2017).

Furthermore, according to the Renewable Energy Prospective (Table 5), wind and solar have the largest potentials capable to generate up to 87,600 GWh/year and 6,500,000 GWh/year respectively. However, it is important to mention that due to technical, environmental and social limitations, are only exploitable 25% of the potential from wind sources (21,900 GW/h) and 3.5% from the solar potential (227,500 GW/h) (SENER, 2017).

Table 5. Renewable Energy Potential (SENER, 2017)

Source	Potential		
	National Projection (MW)	Renewable Energy Perspective (GWh/year)	In this study (PJ)
Geothermal	1,932	2,610	9
Hrydro	8,663	4,920	18
Wind	12,000	21,900	79
Solar	8,000	227,500	819

Nevertheless, other studies suggest different estimations about the renewable potential in Mexico. As stated by Perez-Denicia et.al, Mexico has wind sources to install 40,000 MW, geothermal sources with the potential to install 7,422 MW, hydropower potential of 6,300 MW and solar potential of 5,000,000 MW (Pérez-Denicia, Fernández-Luqueño, Vilariño-Ayala, Montaño-Zetina, & Maldonado-López, 2017). On the other hand, IRENA suggest potential geothermal resources to install 5730 MW; 50,000 MW of wind resources; 9,243 MW of hydro and 5,000,000 MW of solar resources ((IRENA, 2015).

Additionally, IEA estimates a potential of 13400 MW of geothermal reserves and 30,000 MW of hydropower sources (IEA, 2017). In addition, other researchers claim that only the Valley of Mexico has geothermal reservoirs capable to support the installation of 0.45 TW of new capacity (Lenhardt & E.Götz, 2015). Similarly, others have estimated a potential from hydropower energy in 400 MW, considering only the resources in the states of Veracruz and Puebla (Cancino-Solorzano, Paredes-Sánchez, Gutiérrez-Trashorras, & Xiberta-Bernat, 2016). Next table 6 summarizes the renewable energy potential in Mexico according to other researchers and institutions.

Table 6. Suggested renewable potential from other studies (PRODESEN, 2017) (IRENA, 2015)

Technology	Potential (MW)				
	PRODESEN	IRENA	IEA	Alemán-Nava et. al	Pérez-Denicia et. al
Wind	12,000	50,000	30,000	45,200	40,000
Geothermal	1,932	5,730	13,400	7,560	456,000
Hydro	8,763	9,243	-	400	6,300
Solar	8,000	5,000,000	5,000,000	-	5,000,000

5 Modeling process

5.1 OSeMOSYS

OSeMOSYS calculates the lowest Net Present Value (NPV) cost of the objective function, which computes the total costs associated with the modeled energy system (i.e. operating costs, investment costs, emission production penalties and the salvage values) when it is minimized through a linear optimization process (Howells, et al., 2011) (Beltramo, et al., 2018).

The result obtained after the minimization process provides the most cost effective electricity mix that is capable to meet the electricity demand input during the modeling process. As in any optimization problem, the objective function is also subjected to diverse constraints (Howells, et al., 2011). The objective function is a function of the year (*y*), technology (*t*) and region (*r*) (Krikštolaitis, Martišauskas, & Augutis, 2015):

Objective Function

$$Minimize \sum_{y}\sum_{t}\sum_{r} TDC_{x,y,r} = DOC_{x,y,r} + DCI_{x,y,r} + DTEP_{x,y,r} - DSV_{x,y,r} \quad \forall y,t,r;$$

Where:

$TDC_{x,y,r}$ represents the Total Discounted costs.

$DOC_{x,y,r}$ represents the Discounted Operating Costs.

$DCI_{x,y,r}$ represents the Discounted Capital Investment.

$DTEP_{x,y,r}$ represents the Discounted Technology Emissions Penalty.

$DSV_{x,y,r}$ Represents the Discounted Salvage Value.

Furthermore, the model is defined by a series of sets and parameters. The sets "define the physical structure of the model". The sets are usually kept constant over the scenarios. On the other hand, the parameters are the numerical data input directly to the model by the user, and usually some of them vary when different scenarios are performed (Beltramo, et al., 2018).

5.2 Mexican Reference Energy System (RES)

The Mexican Reference Energy system (RES) (figure 7) was developed to understand the interconnections between fuels and energy conversion technologies. The RES also offered the possibility to have an overview of the current structure of the electricity sector in the country, the processes used to convert those fuels, the technologies used to generate electricity, and the final demand (IEA, 2017).

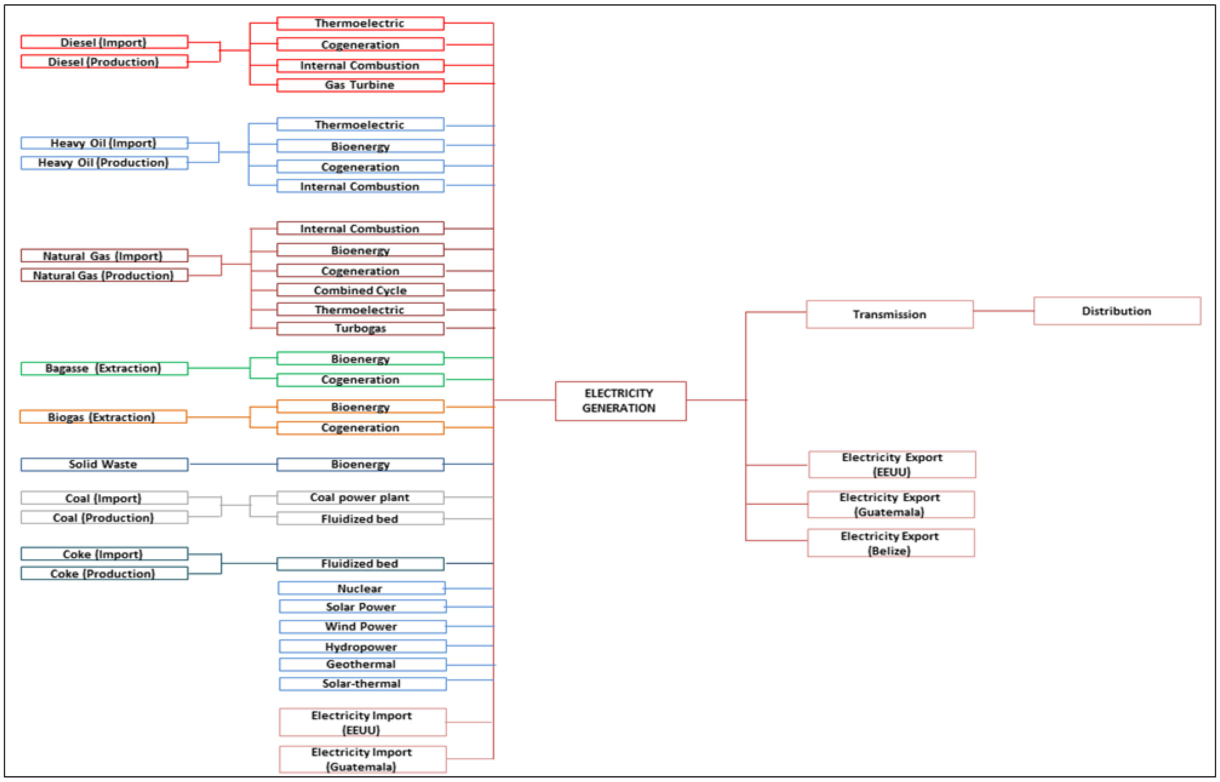


Figure 7. Mexican Reference Energy System (RES) (Author interpretation based on PRODESEN)

5.3 Description of the scenarios

The assessment of the impact of implementing an ETS on the Mexican electricity system required the construction of different scenarios in OSeMOSYS. The first scenario modeled was the BAU scenario, and as defined by the Intergovernmental Panel on Climate Change (IPCC), the BAU is the reference scenario that represents "the state against which change is measured" (IPCC, 2018). The BAU was constructed considering the current infrastructure for power generation, the renewable penetration targets adopted by the Mexican authorities and the projected demand of electricity until 2050. However, the policy to limit and penalize the emission of GHG (i.e. the implementation of an ETS) was not considered in the BAU. It is important to mention that all the assumptions made for the development of the BAU will be presented in section 5.1.5. After the development of the BAU was finished, ten different scenarios were elaborated in order to project the behavior of the electricity system under different conditions; in this case the new conditions assumed the adoption of an ETS (i.e. penalty and limit on emissions). It is important to mention that all the assumptions made for constructing the BAU were maintained in the new scenarios.

Ten different scenarios were built. From scenarios 1 to 5 (Figure 8), the emissions were limited 22% below the emissions projected in the BAU. This limitation represented the Unconditional Nationally Determined Contributions embraced by Mexico. Consequently, a different emission penalty was applied in each one of the five scenarios (Scenario 1: 2.5 USD/t$CO_{2eq.}$, Scenario 2: 7.5 USD/t$CO_{2eq.}$, Scenario 3: 15 USD/t$CO_{2eq.}$, Scenario 4: 30 USD/t$CO_{2eq.}$, and Scenario 5: 50 USD/t$CO_{2eq.}$) under each assumed limit on emissions. These penalty rates were chosen based on the historic prices for the European Union Allowances from 2005 to 2016 (European Environment Agency, 2017). On the other hand, in the models 6 to 10 (Figure 8) the emissions were limited 50% under the emissions forecasted in the BAU. This limit on emissions represents the commitment acquired by the Mexican authorities to reduce the emission of GHG under the Conditional Nationally Determined Contribution. The emission penalties employed were (Scenario 6: 2.5 USD/t$CO_{2eq.}$, Scenario 7: 7.5 USD/t$CO_{2eq.}$, Scenario 8: 15 USD/t$CO_{2eq.}$, Scenario 9: 30 USD/t$CO_{2eq.}$, and Scenario 10: 50 USD/t$CO_{2eq.}$).

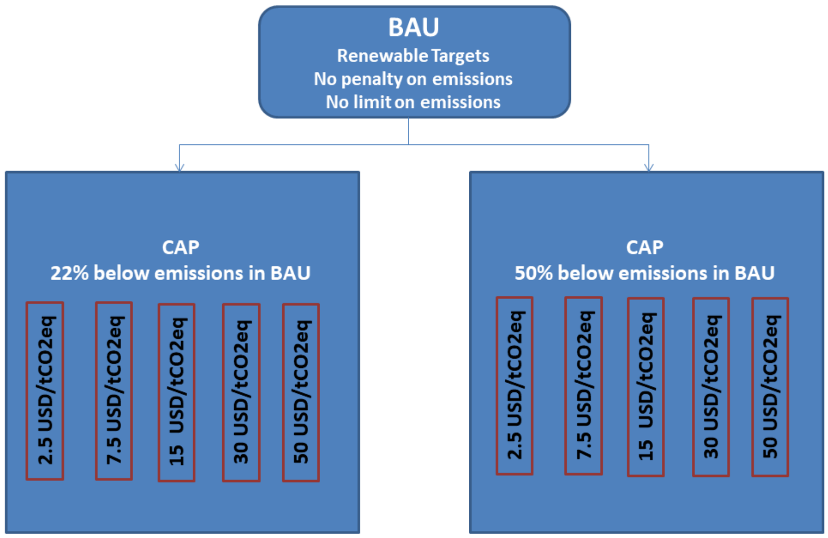


Figure 8. Description of the Scenarios

5.4 Development of the BAU scenario

As previously mentioned, the use of energy models helps policy makers to explore and forecast scenarios and the implication of adopting different policies and strategies (Herbst, Toro, Reitze, & Jochem, 2012). As a result, it was necessary to have the reference scenario to compare the future projections based on the current and future infrastructure, electricity demand and targets adopted by the Mexican authorities.

The first step was the definition of the fuels and the conversion technologies that constitute the Mexican Energy System. Based on official information, fuels used for electricity generation in Mexico are: natural gas, coal, heavy fuel oil, nuclear, municipal solid waste, and sugar cane bagasse (PRODESEN, 2017). Furthermore, for modeling purposes, wind, solar, water and steam were also considered as “fuels”.

On the other hand, the conversion technologies were also defined according to available data published online by the authorities in the National projections (PRODESEN, 2017). Among the energy conversion technologies considered are combined cycle, conventional thermal power plant, conventional coal fired power plant, gas fired power plant, fluidized bed, internal combustion engines, solar photovoltaic (PV), hydropower nuclear power, wind onshore, geothermal power, and bioenergy power plants.

5.5 Data Collection & Assumptions

In the next subsections, the assumptions made for the development of the model are explained. Moreover, the data used to create the model in OSeMOSYS should be unit consistent because the tool itself does not differentiate units. In the Table 7, the units of measurement for the parameters used in the model are shown.

Table 7. Units of measurement considered in the model in OSeMOSYS

Parameter	Unit
AnnualEmissionLimit	kton
AnnualExogenousEmission	kton
CapitalCost	Million USD$/GW
CapitalCostStorage	Million USD$/GW
EmissionActivityRatio	kton/PJ
EmissionsPenalty	Million USD$/kton
FixedCost	Million USD$/GW
ModelPeriodEmissionLimit	kton
ModelPeriodExogenousEmission	kton
ResidualCapacity	GW
TotalAnnualMinCapacityInvestment	GW
VariableCost	Million USD$/PJ

It is important to mention that the development of the model was also limited due to the accessibility to data. The modeling process in OSeMOSYS required information to be assumed to be able to construct the BAU model. The information found in the National Electric System Development Program was a complete source when it comes about data for the total installed capacity, and future capacity additions by technology.

However, it was not possible to obtain specific information about the operational life of each one of the power plants. In addition, PRODESEN publishes average data for costs, efficiencies, life cycle and emissions for the power plants depending on the conversion technology, but it does not provide specific information for each power plant. The PIIRCE (Indicative Program for the installation and retirement of Electric Generation Facilities) provides specific information about the addition and retirement of electric installations until 2031, but it was not possible to exactly determine the capacity to be phased-out after 2031. A more accurate model should be able to consider the life cycle of all the power plants in order to calculate the how much capacity will be phased-out and/or added after 2031.

5.6 Sets

Fuel: The fuels considered in the model are: sugarcane bagasse (BACA), biogas (BIGA), coal (CARB), heavy fuel oil (COMB), coke (COQU), diesel (DIES), natural gas (GANA), and solid waste (RESO), uranium (URAN). In addition, the structure of OSeMOSYS considers electricity as a fuel. For that reason transmission (ELE1) and distribution (ELE3) were also defined as fuels.

Technology: The conversion technologies considered for the reference model are: BIOEBACA bioenergy fueled by sugarcane bagasse, BIOEBIGA-bioenergy fueled by biogas, BIOECOMB-bioenergy fueled by heavy fuel oil, BIOEGANA-bioenergy fueled by natural gas, BIOERESO-bioenergy fueled by municipal solid waste, CAELCARB- coal power plant, CHPEBACA-cogeneration fueled by sugar cane bagasse, CHPEBIGA-cogeneration fueled by biogas, CHPECOMB-cogeneration fueled by heavy oil, CHPEDIES-cogeneration fueled by diesel, CHPEGANA- cogeneration fueled by natural gas, CICOGAN2-combined cycle fueled by natural gas with more than 300MW of capacity, CICOGANA-combined cycle fueled by natural gas with less than 300MW of capacity, COINCOM2-internal combustion fueled by heavy fuel oil with more than 3MW of capacity, COINCOMB- internal combustion fueled by heavy fuel oil with less than 3MW of capacity, COINDIE2-internal combustion fueled by diesel with more than 3MW of capacity, COINDIES-internal combustion fueled by diesel with less than 3MW of capacity, COINGAN2-internal combustion fueled by natural gas with more than 3MW of capacity, COINGANA -internal combustion fueled by natural gas with less than 3MW of capacity, GEOEXTR – Geothermal power, HYDRPOWR-hydropower, LEFUCOQU-fluidized bed-coal, TECOCOMB- thermal power plant fueled by heavy fuel oil, TECODIES-thermal power plant fueled by diesel, TECOGANA-thermal power plants fueled by natural gas, TGASDIE2-gas power plant powered by diesel with more than 42MW of capacity, TGASDIES-gas power plant powered by diesel with less than 42MW of capacity, TGASGAN2-gas power plant powered by natural gas with more than 42MW of capacity, TGASGANA-gas power plant powered by natural gas with less than 42MW of capacity, TSOLPV01-solar PV, WINDONSH-wind onshore, WINDOFFS-wind offshore.

Depreciation Method: the model considers a sinking fund depreciation method.

Discount Rate: It was chosen a discount rate of 10%, following the similar rate use in the PRODESEN (PRODESEN, 2017).

Year: The time span considered is 2017-2050.

Fuel price: The Mexican transmission network is divided in 53 different regions (Figure 4). Depending on the region, there is one specific selling price for each fossil fuel (i.e. coal, heavy fuel, diesel, coke, natural gas and uranium) (PRODESEN, 2017). The selling prices were used to calculate a price variation rate. Subsequently, the variation rate was used to adjust the variable costs in the model.

5.7 Parameters

Annual Electricity Demand: Refers to the electricity demand to be met in PJ. The demand data was obtained from PRODESEN 2017-2031 (Figure 9). To calculate the electricity demand from 2032 to 2050, it was assumed an annual growth rate of 2.9%, which is the same growth rate employed in the PRODESEN (PRODESEN, 2017).

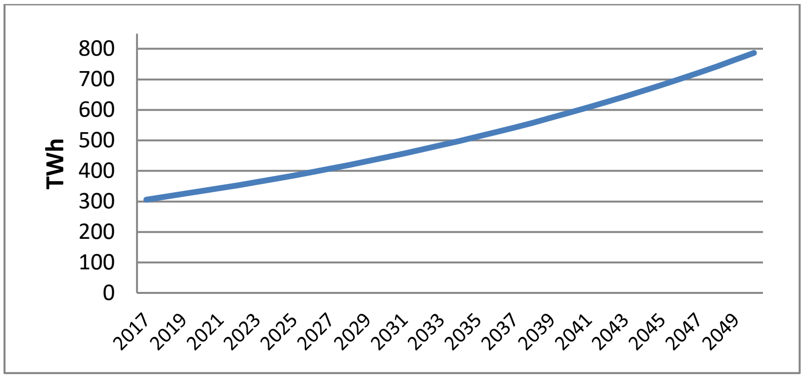


Figure 9. Annual Electricity Demand of Mexico

Availability Factor: This parameter refers to the "Maximum time a technology can run in the whole year, as fraction of the year, ranging from 0 to 1" (OSeMOSYS, 2018). For instance, the availability factor for technologies such as Solar PV was 0.5 as it was assumed it receives solar radiation 50% of the time. The other factors were obtained from the PRODESEN (Appendix 15) (PRODESEN, 2017).

***Capacity Activity Unit*:** As previously described, the most cost-effective solution offers the energy mix (installed capacity) that can meet the projected demand. However, as the demand is given in energy units (PJ), and the capacity is given in power units (GW), it is necessary to use a conversion factor that "represents the energy that should be produced by one unit of power". In this case, the conversion factor is 31.536, and it is used for all the energy conversion technologies (OSeMOSYS, 2018).

Capital Cost: It is the cost of building one power plant in USD per kW. However, to keep the model consistent, the units were modified to USD per GW. The information for the Capital Costs was obtained from PRODESEN 2017-2031. The calculations of the costs from 2032 onwards were calculated using the same methodology previously employed to determine the costs of the fuels. The data used in the model can be found in Appendix 7.

Emission Activity Ratio: The emission activity ratio measures the amount of GHG emitted after the combustion of certain fuel needed to produce one unit of electricity. The units are given in kton/PJ Appendix 9. In the model the emission factors were taken from the Greenhouse Gas Conversion Factors Report published by the British Authorities (UK Government, 2017)Data were found in kgCO_2eq. However, the information was changed to kton/PJ using the next conversion factor:

*Emissions in kton/PJ = (Emissions in kgCO_2eq/0.0000000036)*0.000001*

Input / Output Activity Ratio: The input/output activity ratios define the performance of each one of the conversion technologies. They measure the correlation of fuel consumption and power generation. These two parameters are calculated using the efficiency of the technology. For instance, according to the PRODESEN, the efficiency of a coal fired power plant is between 30% and 40%. In this case, it was assumed an efficiency of 35%, so the input activity ratio is calculated as follows: 1/0.35= 2.85. It can be interpreted as follows: 2.85 units of fuel (input ratio) generate 1 unit of power (output ratio). For all the technologies, the ratio was calculated according to the values in the PRODESEN (PRODESEN, 2017). Appendix 12.

Operational Life: This parameter reflects the time that each power plant is expected to run. In this case, the operational life that the government provides in the PRODESEN was assumed (PRODESEN, 2017). The data used in the model are in Appendix 10.

Fixed and Variable Costs: Data about the fixed costs (Appendix 8) were obtained from the PRODESEN 2017 (PRODESEN, 2017). However, they were adjusted according to the cost projections analyzed by the World Energy Organization in the document "Power generation assumptions in the New Policies and 450 Scenarios in the World Energy Outlook 2016". The Power generation assumptions document provides the projection of fixed and variable costs until 2040. The methodology used to adjust the fixed costs is described as follows. It was first calculated the percentage that prices vary each year, e.g. if the projected fixed cost for certain technology in 2031 was \$1000 and in 2032 was \$1010, the price varies 1%. Then the final fixed cost in 2032 considers the 1% variation. This procedure was used to calculate the fixed costs from 2031 until 2050.

The variable costs (Appendix 11) used in the BAU model were obtained also from the PRODESEN 2017-2031. Furthermore, the variable costs were adjusted according to a variation ratio in the selling price of the fossil fuels. To obtain this fuel variation ratio, it was used the projection about the fuel selling price published in the PRODESEN. As previously mention, the Mexican electricity network is divided in 53 regions, for each one of these regions the price for each fossil fuel can varies, specifically for coal, natural gas, heavy fuel oil and diesel. For coke and uranium there is only one price, so for those fuels there was no need to calculate the average price. PRODESEN projects the future prices for all the fuels in the 53 regions, from 2017 to 2031. The average prices were then calculated for each fossil fuel, and per year from 2017 until 2031. To calculate the variable costs from 2032 to 2050, it was followed the same methodology employed explained before for the calculation of the fixed costs.

The variation rate was calculated based on the projection published in the PRODESEN (SENER, 2016). In the document, the analysis offers the price estimation from 2017 to 2031 for coal, natural gas, heavy fuel oil, diesel, coke and uranium.

REMinproductionTarget: Targets for renewable electricity generation from clean sources were considered according to official information published by the Mexican authorities. The targets were input as percentage of total electricity produced. For instance, by 2018 it has been set a target of 24.9% of electricity generated by clean sources. In the model, the input was 0.25 in 2018. The other targets considered are: 35% (0.35) by 2024, 40% (0.40) by 2035 and 50% (0.50) by 2050 (IRENA, 2015).

Residual Capacity: This parameter "represents the available capacity from the period prior to the first modeling year" (Almulla, et al., 2017). According to the information published in PRODESEN about installed capacity, future projections for capacity installations and phasing out capacity from 2017 to 2031 (SENER, 2017). This information was used to calculate the Residual Capacity from until 2031. Next, there is an example about how the residual capacity was calculated for 2017 and 2018. The same logic was followed for the calculations from 2019 onwards:

Residual Capacity in 2017 = Installed Capacity in 2016 – Phased out capacity in 2017

Residual Capacity in 2018 = Residual Capacity in 2017 – Phased out capacity in 2018

As there is no detailed information about the operational life for each power plant, it was assumed a retirement of capacity of 1% each year after 2040 (Appendix 14).

TotalTechnologyAnnualActivityUpperLimit: As mentioned in section 4.5 (Renewable Energy Potential), the potential electricity generation from renewable sources is limited. In this case, the model was constructed using the official data published in the Renewable Energy Prospective in order to limit the power generation from clean sources (SENER, 2017). In this study, the renewable energy potential used was specified in Table 5. The annual activity upper limit for the other technologies was assumed to be unlimited, so it was not restricted.

TotalAnnualMinCapacityInvestment: The PRODESEN offers information about future capacity to be installed in the country, starting in 2017 until 2031. Based on this publication, the data were used in the model to indicate the capacity to be added each year until 2031 (PRODESEN, 2017) **.** From 2032 onwards, no data was input to avoid any type of influence and to let OSeMOSYS to calculate the capacity required to supply the electricity input in the model. The data used can be found in the Appendix 13.

Emission Penalty: As mentioned in section 3.5.3 (General Law on Climate Change) under an emission trading scheme, the firms obligated to abate emissions are required to buy emission allowances when they cannot comply with the reduction targets imposed by the authorities within their own premises. As a matter of fact, the price of the allowances should be lower than the penalty established for not achieving the reduction goal, otherwise the companies would chose to pay the fine instead of buying the allowances.

The emission penalties employed in this study were presented in section 5.1.3 (Description of the scenarios).

5.8 Validating the BAU Scenario

The results obtained for installed capacity and electricity generation from the BAU scenario in 2017 and 2031 were validated against the national projection by the Ministry of Energy published in the National Electric System Development Program: PRODESEN 2017-2031 (PRODESEN, 2017). The national projection described the present Mexican electricity system as well as the future installed capacity and electricity generation by technology until 2031. The installed capacity and electricity generation of BAU scenario was validated to make sure that the BAU for year 2017 and 2031 followed the trend as specified in national projection reported in the PRODESEN. Table 8 shows the share of installed capacity in 2017 and 2031 in the national projection and the OSeMOSYS model.

Table 8. Share of installed Capacity. 2017 & 2031 (PRODESEN vs OSeMOSYS)

Technology	2017		2031	
	National Projection	This study	National Projection	This study
Combined Cycle	37.6%	38.60%	39.0%	39.8%
Conventional Thermoelectric	16.2%	15.30%	1.8%	1.8%
Coal-fired	7.2%	6.76%	3.6%	3.5%
Gas-Fired	5.6%	6.12%	3.4%	3.9%
Internal Combustion	1.9%	1.99%	1.6%	1.7%
Fluidized bed	0.8%	0.73%	0.9%	0.5%
Hydropower	16.9%	16.34%	12.6%	12.5%
Wind	5.8%	6.21%	15.2%	15.2%
Geothermal	1.2%	1.19%	1.9%	1.8%
Solar	0.7%	0.79%	6.9%	6.7%
Nuclear	2.2%	2.14%	5.0%	4.9%
Bioenergy	1.3%	1.38%	2.0%	2.0%
Efficient CHP	2.6%	2.44%	6.0%	5.8%

The installed capacity in 2017 and in 2031 (Figure 10 and Figure 11) show similar share of installed capacity by technology in each model. The slight differences between the results in both projections (National Projection and This study) in 2017 were due to the data used to simulate the installed capacity for the model in OSeMOSYS and the data used to develop the model employed in the National Projection published in the PRODESEN. This study considered the installed capacity in 2017 and the capacity adjustments planned for 2017. As a result, the new capacity included capacity to be shut down and to be added during 2017.

Furthermore, the model in OSeMOSYS also contemplated capacity additions and retirements published in the Indicative Program for Installation and retirement of Electric Generation Facilities (PIIRCE) (PRODESEN, 2017). The results obtained in 2031 in both simulations also show a similar trend with slight differences (Table 8). The variations perceived in the share of installed capacity by technology in 2031 are multifactorial. First, the model in OSeMOSYS was built assuming a steady trend in the electricity demand for the whole period of the investigation (2017-2050), whereas in the national projection the demand is forecasted only from 2017 to 2031. Another factor that affected the result was the assumed costs and the fluctuation of the prices of the fuels.

As previously described in Figure 4, the transmission network is divided 53 regions, and in each region the prices of the fuels vary. The national projection in PRODESEN differentiates each region and the prices of the fuels, while the model in OSeMOSYS did not differentiate the regions, and only considered an average fuel price.

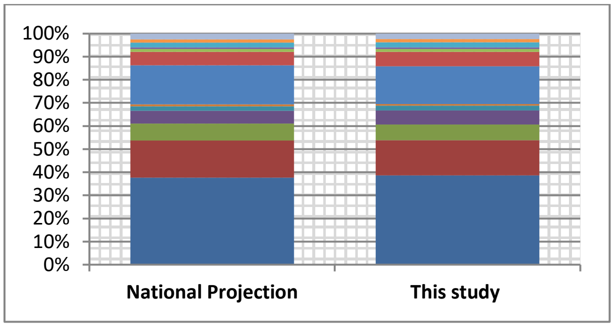


Figure 10. Share of Installed Capacity (%) in 2017

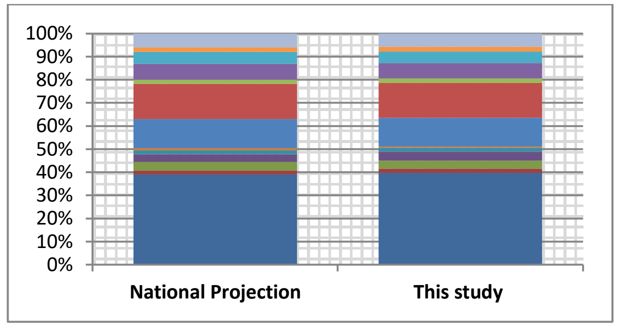
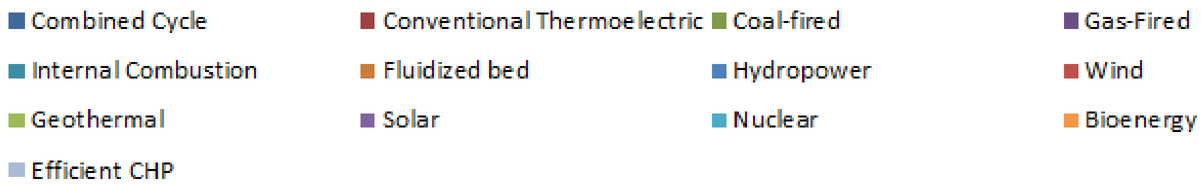


Figure 11. Share of Installed Capacity (%) in 2031



6 Results

Before presenting the results, it is important to recapitulate the research questions that motivated this study:

- *How will the adoption of a Cap and Trade System affect the achievement of the targets set for renewable penetration (i.e. electricity generation) in the country?*

- *What is the most cost-effective policy mix (emission limit - emission penalty) to leverage the Mexican electricity sector into a more sustainable future?*

In order to answer to those questions, the results obtained from the simulations were analyzed individually to understand how the interaction between the adoption of an emissions cap and a penalty on emissions affect the electricity generation targets proposed by the Mexican authorities by 2024 (35%), 2035 (40%) and 2050 (50%).

Nevertheless, the total results for emissions, evolution of installed capacity per scenario, and evolution of the power generation per scenario can be found in the Appendix 1 and Appendix 2 (emissions), Appendix 3 and Appendix 4 (Evolution of installed capacity), Appendix 5 and Appendix 6 (Evolution of Power generation).

6.1 BAU scenario

The results of the BAU scenario showed that when a penalty and a limit on emissions were not adopted, the emissions increased from 2019 onwards (Figure 12). Moreover, the renewable power generation targets were not met (Figure 13).

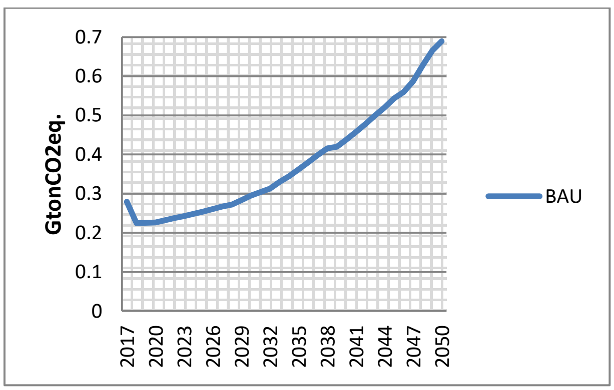


Figure 12. BAU projected emissions

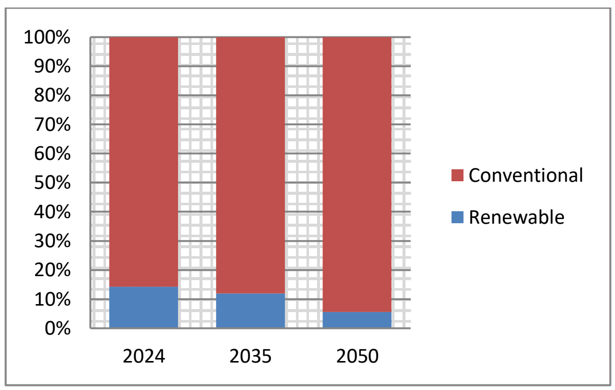


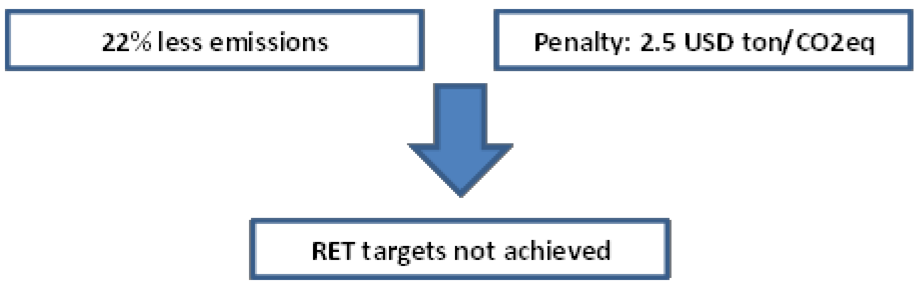
Figure 13. Share of renewable power generation (%) in BAU

According to the simulation, the results obtained in the BAU for power generation, it was mostly obtained from conventional technologies.

The share of renewables had a minor role in the production of electricity. By 2050, the share of electricity generation from gas turbines (including both below and above 42 MW of capacity) fueled by diesel would account for 47.10% and 3.25% from gas turbines (including both below and above 42 MW of capacity) fueled by natural gas. On the contrary, the share of combined cycle power plants fueled (including both below and above 300 MW of capacity) by natural gas would account for 35.13%. In the BAU scenario, the share of power generation from coal power plants reached 3.83%. The penetration of renewables only accounted for 5.65% of the total share for electricity generation (e.g. 1.65% from wind power, 0.68% from solar power, 2.60% from hydropower, 0.30% from geothermal and 0.38% from bioenergy).

6.2 Scenario 1

In the scenario 1, the objective was achieving 22% less emissions by 2031, and keeping the same level of GHG emissions until 2050, by imposing a penalty on emissions of 2.5 USD/tCO_2eq.



The results of the simulations showed that Mexico can comply with the unconditional INDC by 2031. In this scenario the emissions were reduced 22% by 2050 compared to the emissions projected in the BAU. According to the simulations, the emissions decreased from 12.87 Gt/CO_2eq in the BAU, to 10.04 Gt/CO_2eq in this scenario (Figure 14). However, the targets of electricity generation from clean sources were not achieved in this scenario (Figure 15). According to the results, by 2024 only 14.10% of the power generation would be obtained from clean sources. By 2035 the electricity generation from renewables would achieve 12.83%, and by 2050 the power generation obtained from renewables would account for 30.89%, almost 20% below the target.

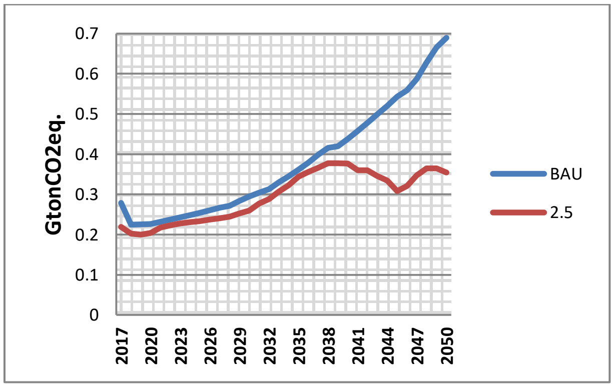


Figure 14. Projected emissions (BAU vs 2.5 USD penalty) 22% less GHG

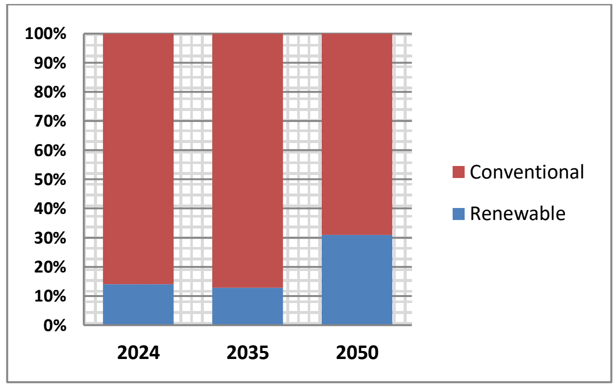


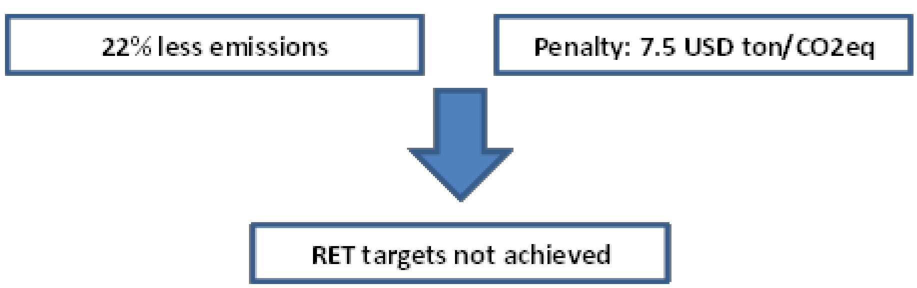
Figure 15. Renewable power generation (%) 2.5 USD penalty & 22% less emissions cap

In this scenario, the share of electricity obtained from combined cycle power plants (including both below and above 300 MW of capacity) fueled by natural gas, increased compared to the results in the BAU. The share rose from 35.13% in the BAU to 54.40% in scenario 1. Furthermore, the share of gas turbine power plants (including both below and above 42 MW of capacity) fueled by diesel decreased to zero in this scenario, and the share of gas turbine power plants (including both below and above 42 MW of capacity) fueled by natural gas increased from 3.25% in the BAU to 12.16% in scenario 1.

On the other hand, penetration of renewables increased compared to the BAU. In the scenario 1, the penetration of solar power plants reached a share of 26% whereas in the BAU the penetration rate only achieved 0.68%. By 2050, the total share of renewables attained 30.88% in scenario 1.

6.3 Scenario 2

In this scenario, the goal was about achieving 22% of emissions reduction by 2031, and keeping the same level until 2050. Additionally, imposing a penalty of 7.5 USD/tCO_2eq.



The results obtained from the simulations showed that Mexico would attain a 22% GHG reduction by 2031. In this scenario Mexico also complies by 2050 with the unconditional INDC adopted by the Mexican authorities. According to the results of the simulations, the emissions decreased from 12.87 Gt/CO_2eq in the BAU, to 10.04 Gt/CO_2eq in this scenario (Figure 16). On the other hand, the targets of electricity generation from renewables were not attained in this scenario (Figure 17). The penetration of renewables achieved only 14.10%, so the 35%

penetration target was not met. By 2035 the electricity generation from renewables would achieve the same penetration rate as in the scenario 1 (12.83%). Finally, by 2050 the power generation from clean sources would achieve 30.97%.

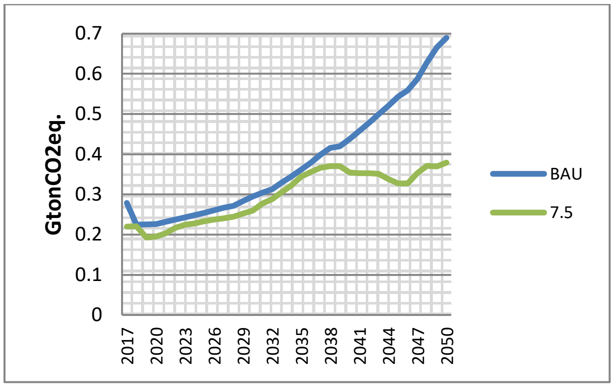


Figure 16. Projected emissions (BAU vs 7.5 USD penalty) 22% less GHG

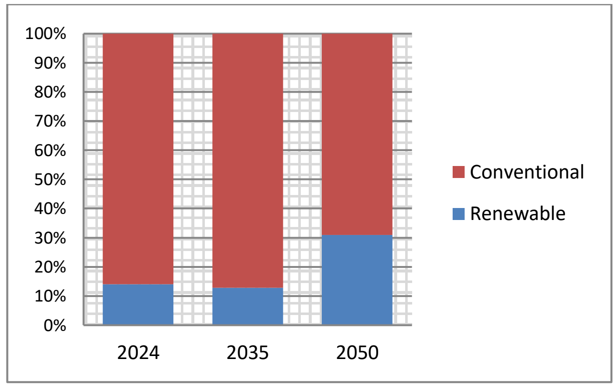
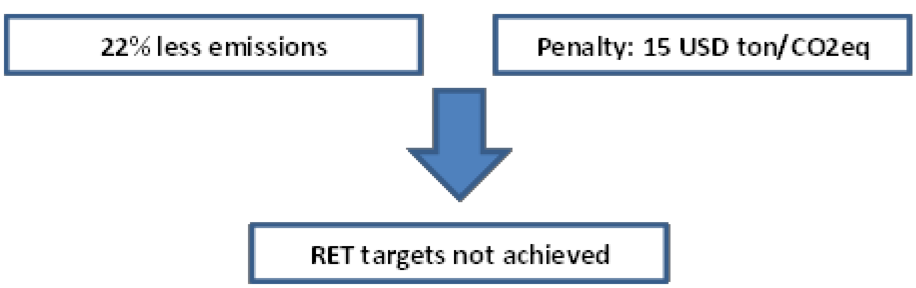


Figure 17. Renewable power generation (%) 7.5 USD penalty & 22% less emissions cap

In the scenario 2, the penalty was set in 7.5 USD/tCO2eq. The share of conventional technologies was dominated by combined cycle power plants (including both below and above 300 MW of capacity) fueled by natural gas reached 50.68%, 3.72% less than in the scenario 1. Moreover, in this scenario the share of generation form coal power plants was not relevant, as it attained no share of power generation. Nonetheless, the shares of renewable power plants 30.96%, with more penetration of solar power plants (26.03%), hydropower (2.61%), wind power (1.65%), geothermal (0.30%) and others (0.39%).

6.4 Scenario 3

The targets to be attained in this scenario, were about achieving 22% of emissions reduction by 2030, and keeping the GHG emissions levels under the same limit until 2050, and imposing penalty of 15 USD/tCO2eq.



The results obtained in the simulations for the scenario 3 demonstrated that Mexico would achieve a 22% GHG reduction, compared to the emissions projected in the BAU (Figure 18). In this scenario the unconditional INDC adopted was satisfied by 2031 and by 2050. Moreover, the results of the simulations showed that the GHG emissions followed the same reduction pattern as in the previous two scenarios. The emissions decreased from 12.87 Gt/CO_2eq in the

BAU, to 10.04 Gt/CO_2eq in this scenario. Nonetheless, the generation targets from renewables were not attained in this scenario (Figure 19). The penetration of renewables achieved only 14.24% by 2024; as a result the 35% penetration target was not achieved. By 2035 the electricity generation rate from renewables only achieved 12.83%. Eventually, by 2050 the power generation from renewables achieved 30.97% share of penetration.

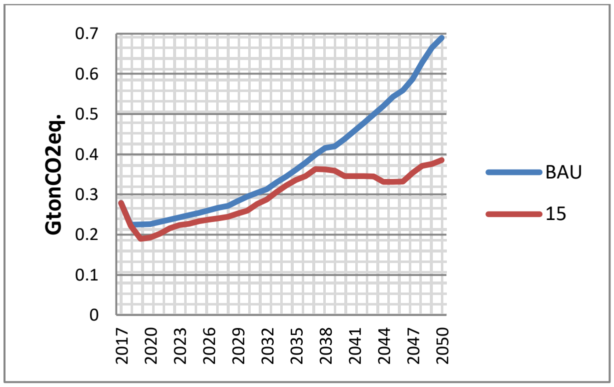


Figure 18. Projected emissions (BAU vs 15 USD penalty) 22% less GHG compared to BAU

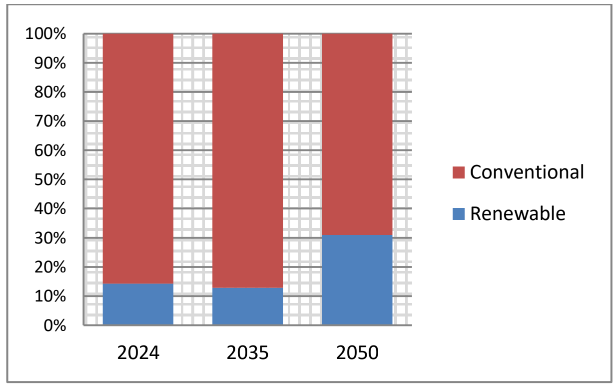


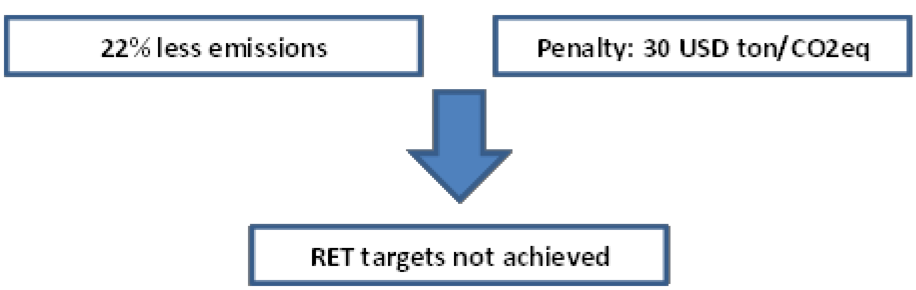
Figure 19. Renewable power generation (%) 15 USD penalty & 22% less emissions cap

The results obtained for the scenario 3 showed that the penetration of renewables attained the same shares as in the scenario 2 (Section 7.3) (e.g. 26.03% of solar power plants, 2.61 % of hydropower, 1.65% of wind power plants, 0.30% from geothermal and 0.39% from other clean technologies.

The share of electricity generation is highly dominated by combined cycle power plants (including both below and above 300 MW of capacity) fueled by natural gas with a share of 50.44% , followed by gas turbine power plants (including both below and above 42 MW of capacity) fueled also by natural gas, with a total share of 9.47%.

6.5 Scenario 4

The targets to be attained in this scenario, were about achieving 22% of emissions reduction by 2030, and keeping the GHG emissions levels under the same limit until 2050, and imposing penalty of 30 USD/tCO_2eq.



In this scenario, the interaction between the cap and the penalty on emissions showed that Mexico could also achieve a 22% GHG reduction compared to the levels projected in the BAU. According to the results obtained in the simulations, it would be possible to attain a higher reduction rate. In this scenario, the GHG reduction could attain a 32% reduction compared to BAU by 2031.

Additionally, Mexico would meet the unconditional INDC by 2050, by achieving a total reduction of 22% in the whole projection. The simulations showed that the emissions decreased from 12.87 Gt/CO_2eq in the BAU, to 8.75 Gt/CO_2eq in this scenario (Figure 20).

Contrarily, the electricity generation targets from clean sources were not attained in this scenario (Figure 21). The penetration of renewables achieved only 14.09% by 2024. By 2035 the power generation from renewables increased compared to the results in the previous scenarios (1 to 3), and the penetration achieved 28.08%, however, the target was not met. Finally, the penetration rate of renewable power generation attained 30.89% by 2050.

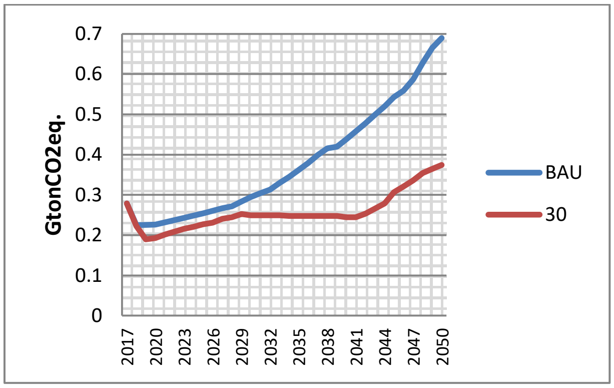


Figure 20. Projected emissions (BAU vs 30 USD penalty) 22% less GHG compared to BAU

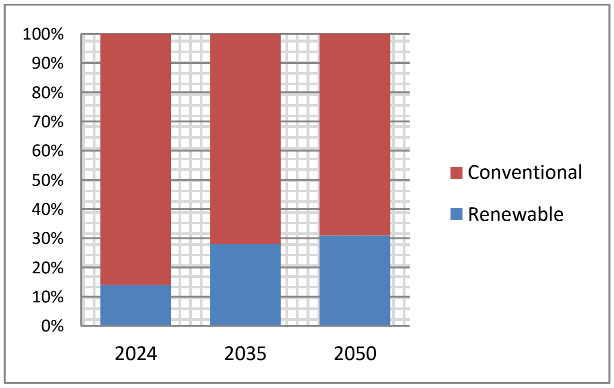
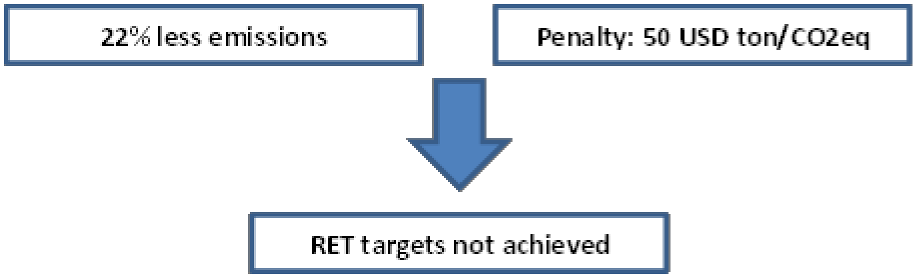


Figure 21. Renewable power generation (%) 30 USD penalty & 22% less emissions cap

The results suggested that if the penalty is set in 30 USD/tCO_2eq the generation from conventional sources would be dominated by combined cycle power plants (including both below and above 300 MW of capacity) fueled by natural gas (53.60%), and gas turbine power plants (including both below and above 42 MW of capacity) fueled by natural gas (9.10%). On the other hand, the share of electricity generation from renewables achieved the largest share by solar power plants (26.03%) and onshore wind power plants (1.65%) by 2050.

6.6 Scenario 5

Finally, in the scenario 5 the objective was achieving 22% less emissions by 2031, and keeping the same level of emissions until 2050, by imposing a penalty on emissions of 50 USD/tCO_2eq.



This scenario was the last one developed considering a cap on emissions 22% below the emissions projected in the BAU. The results suggested that Mexico could meet the unconditional INDC by 2031, and the reduction would reach 38% less emissions by 2050 compared to the estimations in the BAU. In the simulation, the emissions declined from 12.87 Gt/CO_2eq in the BAU, to 7.92 Gt/CO_2eq in this scenario (Figure 22).

On the other hand, the renewable penetration target to be achieved by 2024 was not attained in this scenario, as the penetration only reached 18.79%. Nevertheless, the simulation suggested that by 2035 the power generation from renewables rose to 46.47%. However, the target was not met by 2050, when the penetration of power generation from renewables dropped to 30.89%. Figure 23 shows the rate of power generation in this scenario.

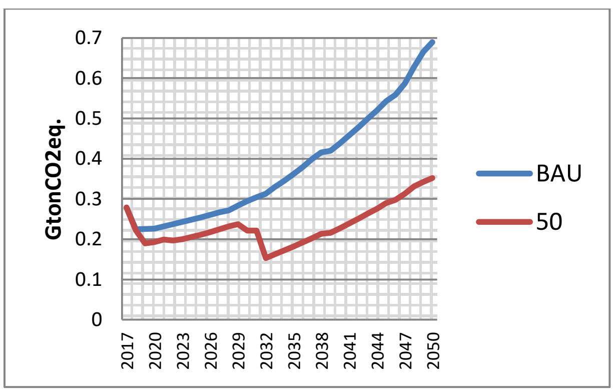


Figure 22. Projected emissions (BAU vs 50 USD penalty) 22% less GHG compared to BAU

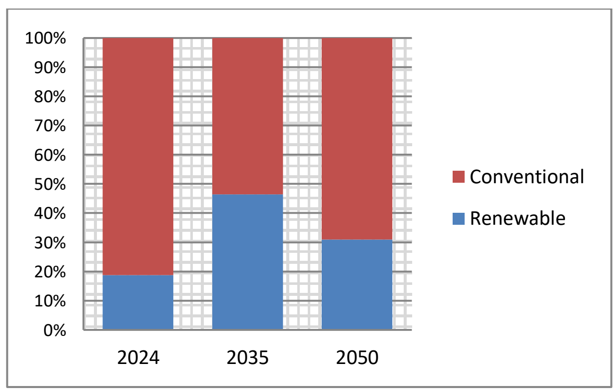
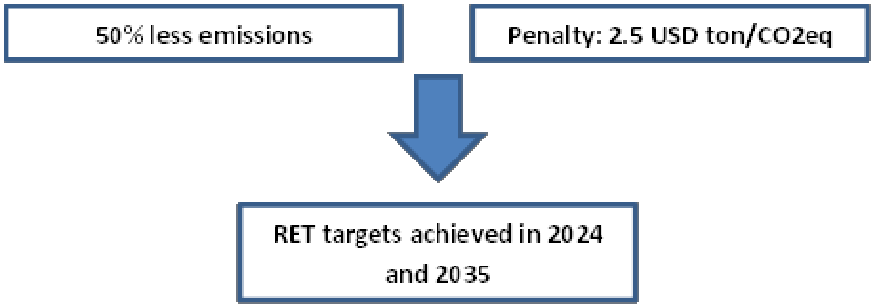


Figure 23. Renewable power generation (%) 50 USD penalty & 22% less emissions cap

The power generation obtained in the last simulation under a 22% less emissions cap showed that when the penalty reached the highest rate (i.e. 50 USD/tCO_{2eq}) the electricity generation by 2050 from combined cycle power plants (including both below and above 300 MW of capacity) fueled by natural gas still had the largest generation share with 53.14%, followed by gas turbine power plants (including both below and above 42 MW of capacity) fueled by natural gas with a power generation share of 14.10%. Moreover, the share of coal power plants disappeared in this scenario. Nevertheless, the share of renewable power generation by 2050 remained similar as in the scenario 1 to 4.

6.7 Scenario 6

This scenario is about achieving 50% of emissions reduction by 2050 and imposing penalty of 2.5 USD/tCO2eq.



The results from the simulations obtained in this scenario showed that Mexico would achieve the reduction targets adopted under the unconditional INDC by 2031 and the conditional INDC by 2050. The total emission levels in this scenario were reduced 50%, compared to the total emissions projected in the BAU. In this scenario, the emissions diminished from 12.87 Gt/CO_2eq in the BAU, to 6.44 Gt/CO_2eq (Figure 24). Furthermore, the electricity generation targets from clean sources were achieved in this scenario by 2024 and 2035, but not by 2050 (Figure 25). The results of the simulation, suggested that 61.16% of the power generation would be obtained from renewables by 2024, and 46.48% by 2035. Nevertheless the penetration of renewables decreased by 2050, when the power generation share from renewables only reached 34.18%.

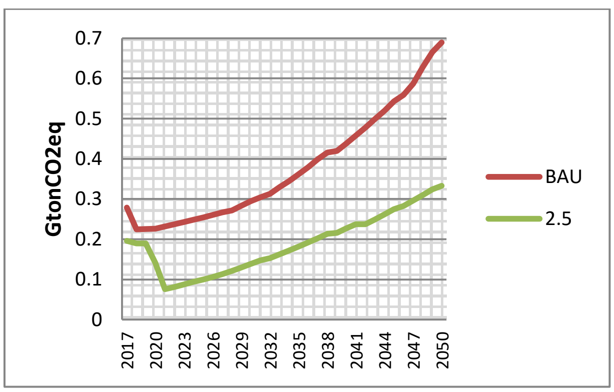


Figure 24. Projected emissions (BAU vs 2.5 USD penalty) 50% less GHG compared to BAU

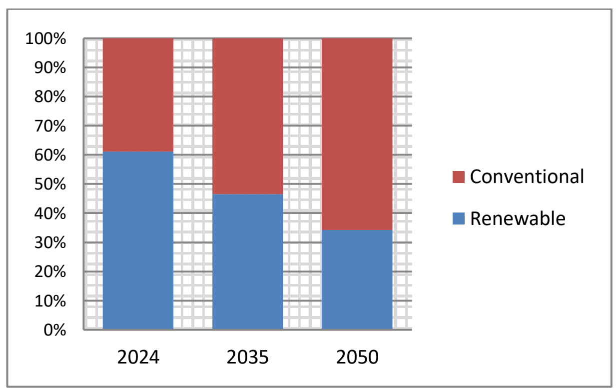


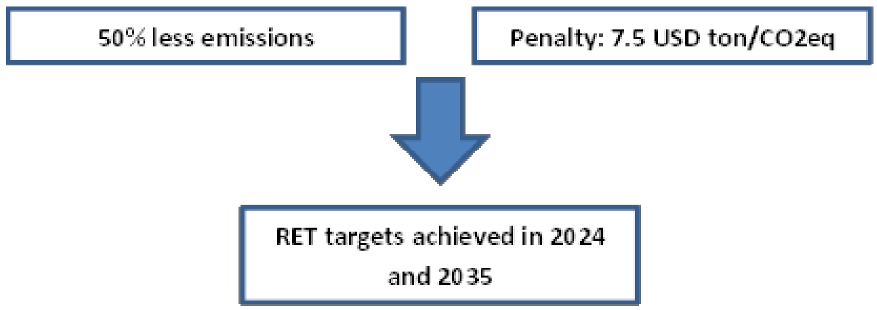
Figure 25. Renewable power generation (%) 2.5 USD penalty & 50% less emissions cap

The power generation in this scenario showed that the share of conventional technologies diminished compared to the scenarios with a less stringent limit on emissions (i.e. cap with 22% less GHG). In this scenario the total emissions were limited 50% below the total emissions projected in the BAU.

By 2050, combined cycle power plants (including both below and above 300 MW of capacity) fueled by natural gas achieved a penetration rate of 35.14% of the total power generation. Additionally, the share of gas turbine power plants fueled by natural gas attained a penetration rate of 29.25% of the total share (27% from gas turbines with capacity below 42 MW and 2.25% from gas turbines with capacity above 42 MW). Additionally, in this scenario the share of onshore wind power plants by 2050 grew 65% compared to the highest penetration rate reached by 2050 in the scenarios when the cap was set 22% below the emissions projected in the BAU. By 2050, the electricity generation share of onshore and offshore wind power plants reached 2.51% of each technology.

6.8 Scenario 7

This scenario was about achieving 50% of emissions reduction by 2050 and imposing penalty of 7.5 USD/tCO_2eq.



The outcome from the simulations in the scenario 7 showed the same trend as the results in the scenario 6 for emission reduction and renewable penetration. In this case, Mexico complied with the commitment to reduce 50% of the GHG emissions by 2050, according to the unconditional and conditional INDC's. The emissions decreased from 12.87 Gt/CO_2eq in the BAU, to 6.44 Gt/CO_2eq in this scenario (Figure 26). Furthermore, the penetration of renewables achieved 61.10% by 2024, so the 35% penetration target was met. Moreover, by 2035 the electricity generation from renewables attained 46.48%. Finally, the share of electricity from clean sources diminished by 2050, when the share of renewable generation achieved 34.18% (Figure 27).

With a penalty fixed in 7.5 USD/tCO_2eq and 50% fewer emissions, the share of power generation from conventional technologies in 2050 were dominated by combined cycle power plants fueled by natural gas. The share of this technology attained 35.14% (including both, below and above 300 MW of capacity). Moreover, the share of gas turbine power plants fueled by natural gas attained a penetration of 29.25% of the total share (9.30% from gas turbines with capacity above 42 MW and 19.95% from gas turbines with capacity below 42 MW). By 2050, the share of electricity generation from onshore and offshore wind power plants reached 2.51% respectively, and the share of solar PV attained 26.03%.

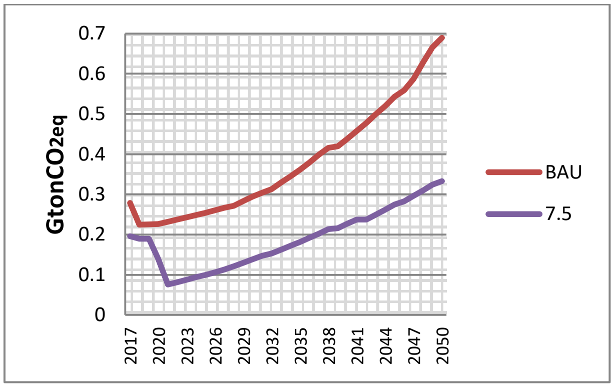


Figure 26. Projected emissions (BAU vs 7.5 USD penalty) 50% less GHG compared to BAU

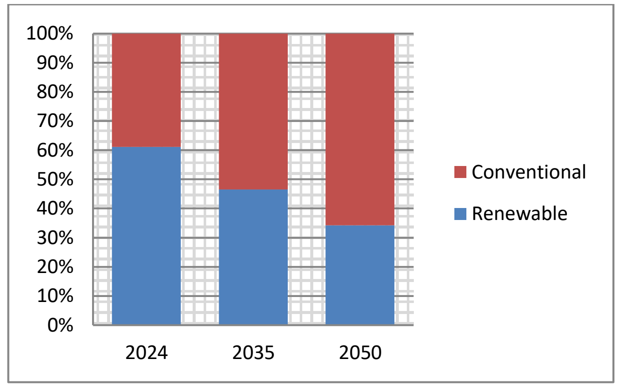
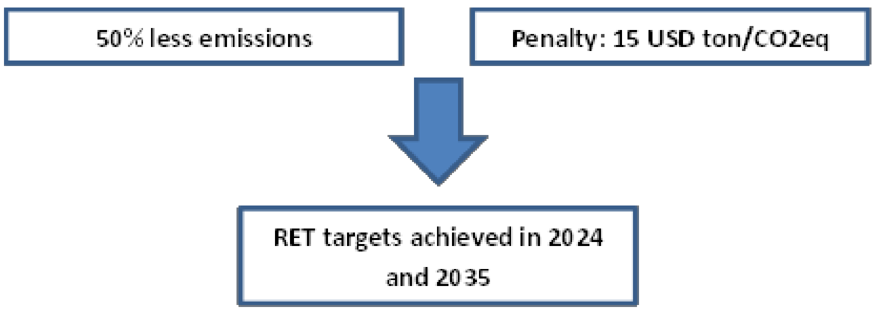


Figure 27. Renewable power generation (%) 7.5 USD penalty & 50% less emissions cap

6.9 Scenario 8

This scenario was about achieving 50% of emissions reduction by 2050 and imposing penalty of 15 USD/tCO_2eq.



The results of the simulations suggested that Mexico can achieve a 50% GHG reduction by 2050 as stated in the conditional INDC adopted. The total emissions decreased from 12.87 Gt/CO_2eq in the BAU, to 6.44 Gt/CO_2eq in this scenario (Figure 28), and the renewable penetration targets were achieved by 2024 (61.10%) and 2035 (46.48%). Nonetheless, by 2050 the power generation share from renewables was almost 20% below the target, and only reached 30.97% of penetration share (Figure 29).

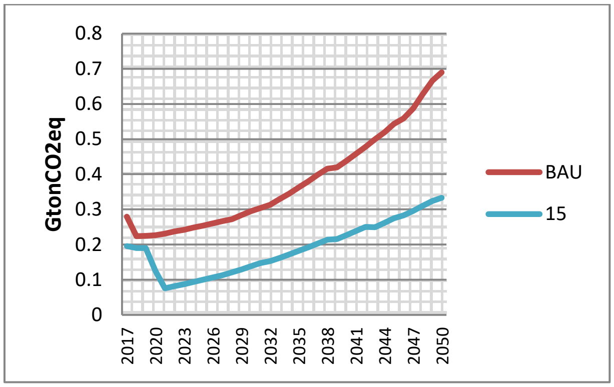


Figure 28. Projected emissions (BAU vs 15 USD penalty) 50% less GHG compared to BAU

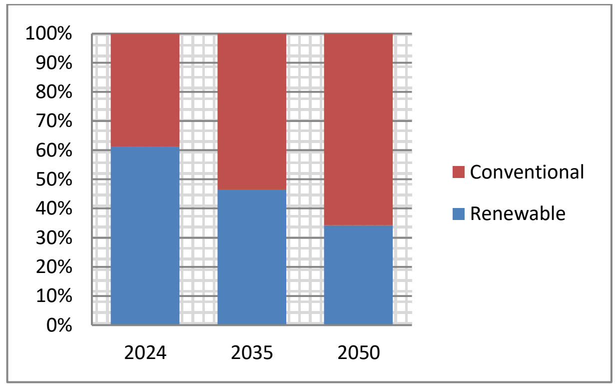
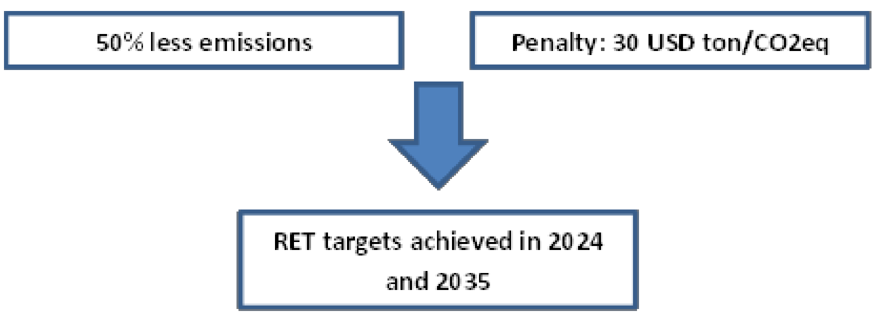


Figure 29. Renewable power generation (%) 15 USD penalty & 50% less emissions cap

6.10 Scenario 9

In the scenario 9, the objective was about achieving 50% of emissions reduction by 2050 and imposing penalty of 30 USD/tCO_2eq.



The results of the simulations of the interaction between the cap and the penalty on emissions showed that Mexico could achieve a 50% GHG reduction by 2050 compared to the emissions projected in the BAU. According to the results obtained in the projection, it would be possible for Mexico to meet the target adopted under the conditional INDC. According to the simulation, the emissions decreased from 12.87 Gt/CO2eq in the BAU, to 6.44 Gt/CO2eq in this scenario (Figure30).

Furthermore, the electricity generation targets from clean sources were attained by 2024 (61 %) and 2035 (46.48%) as shown in Figure 31. On the other hand, the penetration rate of renewables decreased from 46.48% in 2035 to 34.18% in 2050. As a result, the power generation target from clean sources targets was not met by 2050.

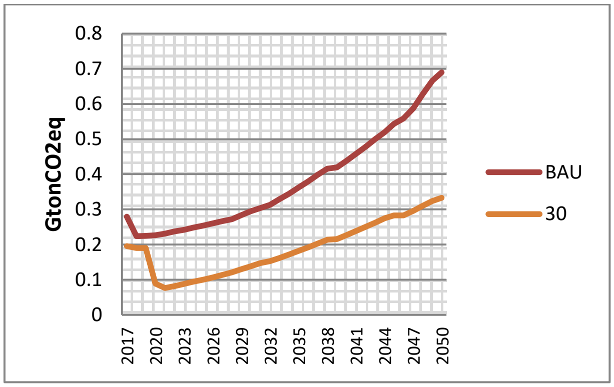


Figure 30.Projected emissions (BAU vs 30 USD penalty) 50% less GHG compared to BAU

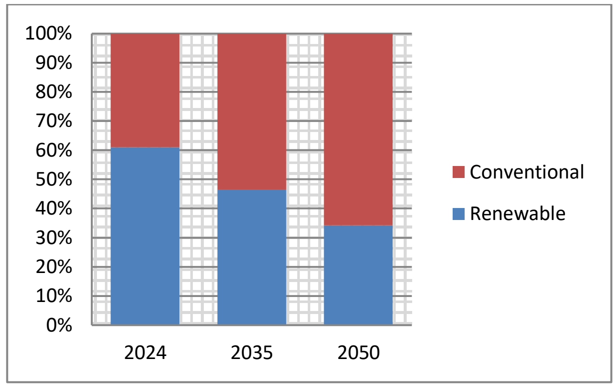
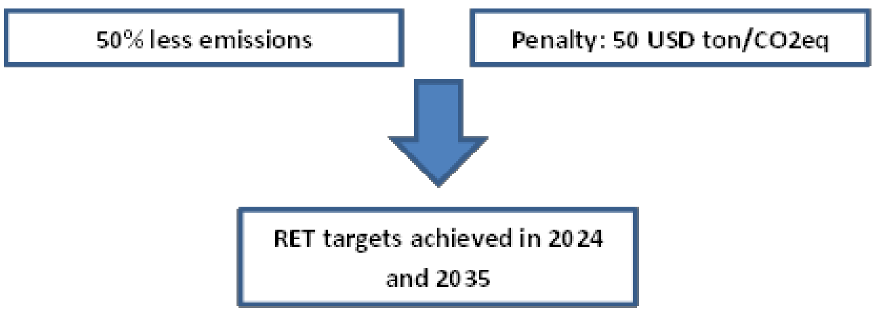


Figure 31.Renewable power generation (%) 30 USD penalty & 50% less emissions cap

6.11 Scenario 10

Finally, this scenario is about achieving 50% of emissions reduction by 2050 and imposing penalty of 50 USD/tCO2eq. In this last scenario, the conditional INDC can be met, according to the projections (Figure 32).



The power generation shares from clean sources were the same as in the previous scenario. The targets were partially achieved in 2024 (61.10%) and in 2035 (46.48%). However by 2050 the target was not achieved, as the penetration rate of renewable sources only attained 34.10% (Figure 33).

The shares of renewable and conventional penetration by 2050 in the scenarios 9 and 10 practically remained the same as in the other scenarios with a limit 50% below the projected emissions in the BAU. The only difference appeared in the electricity generation share from gas fired power plants (both, above and below 300 MW of capacity) fueled by natural gas.

Moreover, by 2050 the share of this technology attained the same penetration rate of 29.25% of the total share; nonetheless, in the scenario 9, 24.75% was from gas turbines with capacity below 42 MW and 4.50% from gas turbines fueled by natural gas with capacity above 42 MW, whereas in the scenario 10, 24.18% was from gas turbines with a capacity below 42 MW and 5.05% from gas turbines with capacity above 42 MW.

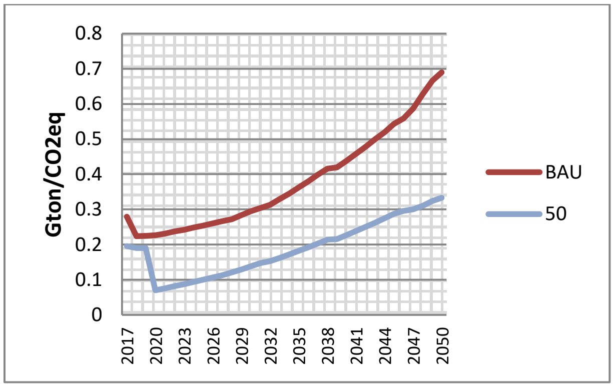


Figure 32. Projected emissions (BAU vs 30 USD penalty) 50% less GHG compared to BAU

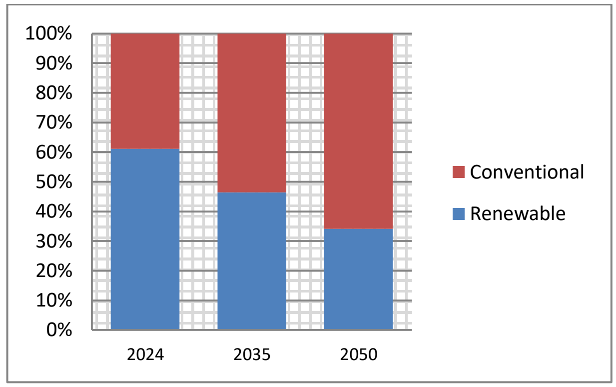


Figure 33. Renewable power generation (%) 50 USD penalty & 50% less emissions cap

7 Conclusions

The results of the simulations indicated that when the emission trading scheme was not implemented (BAU scenario), the emission reduction targets adopted under the Paris agreement were not achieved by either by 2024, 2035 nor 2050. Moreover, the renewable penetration targets set by the authorities were not reached also by the same years (2024, 2035 and 2050). If the ETS was not adopted as an environmental policy, the levels of GHG emissions would progressively increase until the end of the studied period according to the projections in the Business-as-Usual scenario. Furthermore, the results obtained in the BAU for power generation indicated a high dependence on technologies fueled by natural gas (i.e. combined cycle and gas turbine power plants) accounting for power generation share of 83% by 2050. Contrarily, the penetration of renewables only reached 5.62% of the power generation.

On the other hand, when the limit on emissions was set 22% below the GHG projected in the BAU, the results suggested that by 2050, the same share of renewable penetration would be achieved in all the scenarios when a penalty was applied. The renewable technology with the largest share was the solar PV reaching 26.03% of power generation, followed by hydropower plants with a power generation share of 2.61%, then wind onshore with 1.65% electricity share, and geothermal power with 0.30%. The power generation rates described before where achieved in all the scenarios by 2050.

The difference in each scenario was mainly in the penetration of power plants fueled by natural gas. The largest share of gas turbine power plants fueled by natural gas was obtained when the penalty was set in 50 USD/tCO2eq whereas the lowest share (9.01%) was achieved when the penalty was imposed in 30 USD/tCO2eq.
Nonetheless, the largest share of combined cycle power plants fueled by natural gas (54.41%) was attained in the scenario with the lowest penalty on emissions (2.5 USD/tCO2eq), whereas the lowest penetration rate (50.45%) of the same conversion technology was reached in the scenario with a 15 USD/tCO2eq penalty.

Under a more stringent limit on emissions, the cap was set 50% below the projected emissions in the BAU. The results suggested that the renewable penetration targets were partially achieved. According to the simulations, the renewable penetration targets were only achieved by 2024 and 2035 in all the scenarios, but not by 2050. By 2050, the shares of power generation from renewables were similar in all the scenarios. The technology with the largest electricity generation share was solar PV (26.03%), followed by hydropower (2.61 %), and onshore wind power (2.51%). Furthermore, under a more restrained cap the share of wind power generation from offshore wind power was required, attaining a penetration rate of 2.51%, also by 2050.

Similarly to the outcomes obtained in the simulations under a 22% fewer emissions limit, the results in the scenarios with a limit 50% below the GHG in the BAU also suggested a high dependence on conversion technologies fueled by natural gas. According to the simulations, the conventional electricity generation technologies with the largest shares of penetration were combined cycle and gas turbines power plants, both fueled using natural gas.

The renewable penetration rates in all the scenarios suggest that the potential from renewables was totally achieved, and when the limit on emissions was lowered, the penetration of more expensive technologies was required in order to meet the electricity demand. In this study, the power potential from renewables was restricted according to the official information available online, however, as discussed in the section 4.5 (Renewable Energy Potential) different researchers suggest larger potential for solar, wind and geothermal power plants in Mexico.

Finally, the development of the model used in this study required to limit the potential renewable resources to replicate the real natural conditions in the country. However, as mentioned in the section 4.5 (Renewable potential) the official data differs when compared to other sources (i.e. studies and researchers) and that try to The data used work It would be suggested a deeply analysis to study the effect of the cap and trade scheme in the Mexican electricity sector should include higher renewable potential, so the renewable penetration goals and reduction targets would be probably achieved.

8 References

Alipzar-Castro, I., & Carlos, R.-M. (2016). Review of the Mexico's energy Reform in 2013: Background, analysis and the reform and reactions. *Renewable and Sustainable Energy Reviews., 58*, 725-736.

Almulla, Y., Broad, O., Shivakumar, A., Gardumi, F., Ramos, E., Avgerinopoulos, G., et al. (2017, 06). *OSeMOSYS.* Retrieved 05 30, 2018, from osemosys.org: http://www.osemosys.org/uploads/1/8/5/0/18504136/momani_training_manual-_rev170612.pdf

Alpizar-Castro, I., & Rodríguez-Monroy, C. (2016). Review of Mexico's energy reform in 2013: Background, analysis of the reform and reactions. *Renewable and Sustainable Energy Reviews, 58*, 725-736.

Awanthi, M., & Navaratne, C. (2018). Carbon Footprint of an Organization: a Tool for Monitoring Impacts on Global Warming. *Procedia Engineering, 212*, 729-735.

Azemraw Senshaw, D., & Won Kim, J. (2018). Meeting conditional targets in nationally determined contributions of developing countries: Renewable energy targets and required investment of GGGI member and partner countries. *Energy Policy*, 433-443.

Azemraw, D., & Won, J. (2018). Meeting conditional targets in nationally determined contributions of developing countries: Renewable energy targets and required investment of GGGI member and partner countries. *Energy Policy*, 433-443.

Azuz-Adeath, I., & Yañez-Arancibiab, A. (2018). Climate Change: Ecological and socio economic dimensions in the coastal zone. *Ecological Engineering*.

Balibar, S. (2017). Energy transitions after COP21 and 22. *Comptes Rendus Physique*, 479-487.

Barragán-Beaud, C., Pizarro-Alonso, A., Xylia, M., Syri, S., & Silveira, S. (2018). Carbon tax or emissions trading? An analysis of economic and political feasibility of policy mechanisms for greenhouse gas emissions reduction in the Mexican power sector. *Energy Policy*, 287-299.

Beltramo, A., Gardumi, F., Shivakumar, A., Morrison, R., Taliotis, C., Broad, O., et al. (2018). From the development of an open-source energy modelling tool to its application and the creation of communities of practice: The example of OSeMOSYS. *Energy Strategy Reviews*, 209-228.

Benites-Lazaro, L., Gremaud, P., & Benites, L. (2018). Business responsibility regarding climate change in Latin America: An empirical analysis from Clean Development Mechanism (CDM) project developers. *The Extractive Industries and Society*.

BMU. (2018). *Federal Ministry for Environment, Nature Conservation and Nuclear Safety*. Recuperado el 26 de 03 de 2018, de Kyoto Mechanisms: https://www.bmu.de/en/topics/climate-energy/climate/international-climate-policy/kyoto-protocol/kyoto-mechanisms/#c10378

Bramstoft, R., Pizarro Alonso, A., Karlsson, K., Kofoed-Wiuff, A., & Münster, M. (2018). STREAM-an energy scenario modelling tool. *Energy Strategy Reviews*, 62-70.

Cancino-Solorzano, Y., Paredes-Sánchez, J. P., Gutiérrez-Trashorras, A. J., & Xiberta-Bernat, J. (2016). The development of renewable energy resources in the State of Veracruz, Mexico. *Utilities Policy*, 1-4.

Centre on Energy, Climate and Sustainable Development. (01 de 04 de 2018). *UNEP DTU Partnership.* . Recuperado el 05 de 04 de 2018, de CDM projects by host region: http://www.cdmpipeline.org/cdm-projects-region.htm#4

CEPAL. (2004, March). *CEPAL.* Retrieved 04 07, 2018, from https://www.cepal.org/es/publicaciones/5620-mercado-carbono-america-latina-caribe-balance-perspectivas

CEPAL. (03 de 2004). *El mercado de carbono en América Latina y el Caribe: balance y perspectivas.* Recuperado el 25 de 03 de 2018, de El mercado de carbono en América Latina y el Caribe: balance y perspectivas: https://repositorio.cepal.org/bitstream/handle/11362/5620/1/S043136_es.pdf

Chamber of Deputies. (07 de 06 de 2013). *Comisión Reguladora de Energía.* Recuperado el 15 de 07 de 2018, de Ley para el aprovechamiento de Energías Renovables y el financiamiento de la transición energética: http://www.cre.gob.mx/documento/3870.pdf

Chunark, P., Limmeechokchai, B., Fujimori, S., & Masui, T. (2017). Renewable energy achievements in CO2 mitigation in Thailand's NDCs. *Renwable Energy*, 1294-1305.

CMS. (03 de 2017). *A brief overview of the new Mexican Electricity Wholesale Market.* Recuperado el 08 de 09 de 2018, de https://cms.law/en/content/download/300306/7567168/version/1/file/%28S%29%201703-0015%20%28v4%29%20BROC%20Mexico%20Energy%20Reform%20Overview.pdf

Corbera, E., & Jover, N. (2014). The undelivered promises of the Clean Development Mechanism: insights from three projects in Mexico. *Carbon Management*, 39-54.

CRE. (18 de 08 de 2016). *Comisión Reguladora de Energía.* Recuperado el 16 de 02 de 2018, de Comisión Reguladora de Energía: https://www.gob.mx/cre/articulos/preguntas-frecuentes-sobre-los-certificados-de-energias-limpias

Cruz-Cano, D., Elizondo, A., Pérez-Cirera, V., Strapasson, A., & Fernández, J. C. (2017). Mexico’s low carbon futures: An integrated assessment for energy planning and climate change mitigation by 2050. *Futures*, 14-26.

Department of Energy & Climate Change. (09 de 11 de 2015). *The UK's position on Phase IV of EU ETS.* Recuperado el 01 de 04 de 2018, de https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/474050/The_UK_s_position_on_Phase_IV_of_EU_ETS_.pdf

Dhakouani, A., Gardumi, F., Znouda, E., Bouden, C., & Howells, M. (2017). Long-term optimisation model of the Tunisian power system. *Energy*, 550-562.

Dhillon, R., & von Wuehlisch, G. (2013). Mitigation of Global warming through renewable biomass. *Biomass and Bioenergy, 48*, 75-89.

Endres, A., & Ohl, C. (2005). Kyoto, Europe?—An Economic Evaluation of the European Emission Trading Directive. *European Journal of Law and Economics, 19*, 17-39.

English, J., Niet, T., Lyseng, B., Palmer-Wilson, K., Keller, V., Moazzen, I., et al. (2017). Impact ofelectrical intertie capacity on carbon policy effectiveness. *Energy Policy, 101*, 571-581.

English, J., Niet, T., Lyseng, B., Palmer-Wilson, K., Keller, V., Moazzen, I., y otros. (2017). Impact of electrical intertie capacity on carbon policy effectiveness. *Energy Policy*, 571-581.

EPA. (19 de 01 de 2017). *United States Environmental Protection Agency*. Recuperado el 24 de 08 de 2018, de What Is Emissions Trading?: https://www.epa.gov/emissions-trading-resources/what-emissions-trading

Ernst & Young . (14 de 12 de 2015). *Ernst & Young. Ley de Transición Energética.* Recuperado el 26 de 02 de 2018, de http://www.ey.com/Publication/vwLUAssets/ey-ley-de-transicion-energetica/$FILE/ey-ley-de-transicion-energetica.pdf

European Environment Agency. (2017). *Trends and projections in the EU ETS in 2017.* Recuperado el 11 de 11 de 2018, de The EU Emission Trading Scheme in numbers: https://www.eea.europa.eu/publications/trends-and-projections-EU-ETS-2017/at_download/file

Fais, B., Blesl, M., Fahl, U., & Voß, A. (2014). Analysing the interaction between emission trading and renewable electricity support TIMES. *Climate Policy*, 355-373.

Federal Government of Mexico. (16 de 11 de 2016). *Gobierno de México. Prensa Secretaría de Energía*. Recuperado el 27 de 02 de 2018, de Gobierno de México: https://www.gob.mx/sener/prensa/mexico-cumplira-con-su-meta-del-35-de-generacion-electrica-con-energias-limpias-en-2024-consejo-consultivo-para-la-transicion-energetica

Federal Government of Mexico. (19 de 01 de 2018). *Chamber of deputies.* Recuperado el 07 de 15 de 2018, de Ley General de Cambio Climático: http://www.diputados.gob.mx/LeyesBiblio/pdf/LGCC_190118.pdf

Fragkos, P., Tasios, N., Paroussos, L., Capros, P., & Tsani, S. (2017). Energy system impacts and policy implications of the European Intended Nationally Determined Contribution and low-carbon pathway to 2050. *Energy Policy*, 216-226.

Gallo, A. (19 de 11 de 2014). *Harvard Business Review*. Recuperado el 06 de 10 de 2018, de https://hbr.org/2014/11/a-refresher-on-net-present-value

Gao, L., Huang, J., Chen, X., Chen, Y., & Liu, M. (2018). Contributions of natural climate changes and human activities to the trend of extreme precipitation. *Atmospheric Research, 205*, 60-69.

German Emission Trading Authority . (10 de 2017). *Deutsche Emissionshandelsstelle.* Recuperado el 25 de 02 de 2018, de Deutsche Emissionshandelsstelle:

https://www.dehst.de/SharedDocs/downloads/EN/project-mechanisms/case_study_AP3-overview.pdf?__blob=publicationFile&v=2

Government of Canada. (11 de 1992). *THE RIO EARTH SUMMIT:SUMMARY OF THE UNITED NATIONS CONFERENCE ON ENVIRONMENT AND DEVELOPMENT*. Recuperado el 26 de 03 de 2018, de http://publications.gc.ca/Collection-R/LoPBdP/BP/bp317-e.htm

Government of Canada. (2018). *The Québec Cap and Trade System for Greenhouse Gas Emissions Allowances.* Recuperado el 02 de 10 de 2018, de http://www.mddep.gouv.qc.ca/changements/carbone/documents-spede/in-brief.pdf

Graham Research Institute. (08 de 2014). *The Globe Climate Legislation Study.* Recuperado el 02 de 10 de 2018, de Mexico: https://climateobserver.org/wp-content/uploads/2014/08/Mexico_GLOBE_Fourth_Ed.pdf

Graham Research Institute. (01 de 06 de 2016). *Graham Research Institute on Climate Change and the Environment*. Recuperado el 04 de 04 de 2018, de Graham Research Institute on Climate Change and the Environment: http://www.lse.ac.uk/GranthamInstitute/law/general-law-on-climate-change/

Hawkes, A., Pfenninger, S., & Keirstead, J. (2014). Energy systems modeling for twenty-first century challenges. *Renewable and Sustainable Energy Reviews.*, 74-86.

Herbst, A., Toro, F., Reitze, F., & Jochem, E. (2012). Introduction to Energy Systems Modelling. *Swiss Journal of Economics and Statistics, 148*.

Hernandez Alva, C. (2016, 04). *Harvard Kennedy Schoool.* Retrieved 08 10, 2018, from Reform of Electricity Sectors: The Mexican Case: https://sites.hks.harvard.edu/hepg/Papers/2016/hernandez%20alva.%20cepg.%20mexico.pdf

Howells, M., Rogner, H., Strachan, N., Heaps, C., Huntington, H., Kypreos, S., et al. (2011). OSeMOSYS: The Open Source Energy Modeling System: An introduction to its ethos, structure and development. *Energy Policy*, Pages 5850-5870.

Ibarra-Yunez, A. (2015). Energy Reform in Mexico: Imperfect unbunding in the electricity sector. *Utilities Policy*, 19-27.

ICAP. (28 de 02 de 2018). *International Carbon Action Partnership*. Recuperado el 28 de 02 de 2018, de https://icapcarbonaction.com/en/ets-map

ICAP. (09 de 03 de 2018). *International Carbon Action Partnership.* Recuperado el 14 de 07 de 2018, de ETS Detailed Information. Mexico: https://icapcarbonaction.com/en/?option=com_etsmap&task=export&format=pdf&layout=list&systems[]=59

IDLO. (2013). *International Development Law Organization* . Recuperado el 09 de 08 de 2018, de Creating a Culture of Justice: https://www.files.ethz.ch/isn/144159/MexicoClimateChangeLWB.pdf

IEA. (21 de 12 de 2016). *International Energy Agency*. Recuperado el 08 de 04 de 2018, de International Energy Agency. Addressing Climate Change. Policies and Measures Databases : https://www.iea.org/policiesandmeasures/pams/mexico/name-155220-en.php?s=dHlwZT1jYyZzdGF0dXM9T2s,&return=PG5hdiBpZD0iYnJlYWRjcnVtYiI-PGEgaHJlZj0iLyI-SG9tZTwvYT4gJnJhcXVvOyA8YSBocmVmPSIvcG9saWNpZXNhbmRtZWFzdXJlcy8iPlBvbGljaWVzIGFuZCBNZWFzdXJlczwvYT4gJnJhcX

IEA. (2016). *Mexico Energy Outlook.* Recuperado el 09 de 08 de 2018, de International Energy Agency: https://www.iea.org/publications/freepublications/publication/MexicoEnergyOutlook.pdf

IEA. (2017). *Energy Policies Beyond IEA Countries.* Recuperado el 26 de 10 de 2018, de https://www.iea.org/publications/freepublications/publication/EnergyPoliciesBeyondIEACountriesMexico2017.pdf

IEA. (2017). *Energy Policies Beyond IEA countries.* . Recuperado el 14 de 07 de 2018, de Mexico 2017: https://www.iea.org/publications/freepublications/publication/EnergyPoliciesBeyondIEACountriesMexico2017.pdf

IEA. (06 de 06 de 2017). *International Energy Agency. Energy Technology Perspectives 2017*. Recuperado el 08 de 04 de 2018, de International Energy Agency. Energy Technology Perspectives 2017: https://www.iea.org/etp2017/summary/

IETA. (01 de 2018). *Mexico: An Market based Climate Policy Case Study* . Recuperado el 01 de 04 de 2018, de http://www.ieta.org/resources/Resources/Case_Studies_Worlds_Carbon_Markets/2018/Mexico-Case-Study-Jan2018.pdf

INECC. (12 de 11 de 2016). *Instituto Nacional de Ecología y Cambio Climático*. Recuperado el 09 de 08 de 2018, de Acciones de México ante el Cambio Climático, rumbo a la Conferencia de las Partes COP 22 en Marruecos: https://www.gob.mx/inecc/acciones-y-programas/acciones-de-mexico-ante-el-cambio-climatico-rumbo-a-la-conferencia-de-las-partes-cop-22-en-marruecos-80136

INECC. (18 de 05 de 2018). *Contexto Internacional en materia de Cambio Climático*. Recuperado el 09 de 08 de 2018, de Convención Marco de las Naciones Unidas sobre el Cambio Climático: https://www.gob.mx/inecc/acciones-y-programas/contexto-internacional-17057

IPCC. (2018). *Data Distribution Center*. Recuperado el 2018 de 11 de 11, de Definition of Terms Used Within the DDC Pages: http://www.ipcc-data.org/guidelines/pages/glossary/glossary_b.html

IRENA. (06 de 2015). *International Renewable Energy Agency.* Recuperado el 30 de 05 de 2018, de www.irena.org: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_RE_Latin_America_Policies/IRE

NA_RE_Latin_America_Policies_2015_Country_Mexico.pdf?la=en&hash=31908495CBB5E5DC3C61B23949C517B26C611521

IRENA. (05 de 2015). *REMap 2030.* Recuperado el 26 de 10 de 2018, de A Renewable Energy Roadmap: http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_REmap_Mexico_report_2015.pdf?la=en&hash=8A259915297B04B0D50A422EDF48AD87007B56B1

Jano-Ito, M., & Crawford-Brown, D. (2016). Socio-technical analysis of the electricity sector of Mexico: Its historical evolution and implications for a transition towards low-carbon development. *Renewable and Sustainable Energy Reviews*, 567-590.

Jason Veysey, C. O. (2016). Pathways to Mexico's climate change mitigation targets: A multi-model analysis. *Energy Economics*, 587-599.

KPMG. (09 de 2016). *KPMG.* Recuperado el 09 de 08 de 2018, de Opportunities in the Mexican Electricity Sector: https://assets.kpmg.com/content/dam/kpmg/mx/pdf/2016/09/Opportunities-in-the-Mexican-Electricity-Sector.pdf

Krikštolaitis, R., Martišauskas, L., & Augutis, J. (2015). Energy mix optimization from an energy security perspective. *90*, 300-314.

Lenhardt, N., & E.Götz, A. (2015). Geothermal reservoir potential of volcaniclastic settings: The Valley of Mexico, Central Mexico. *Renewable Energy, 77*, 423-429.

LGCC. (19 de 01 de 2018). *Cámara de Diputados.* Recuperado el 02 de 04 de 2018, de Cámara de Diputados: http://www.diputados.gob.mx/LeyesBiblio/pdf/LGCC_190118.pdf

Markets Insider. (2018). *CO2 European Emission Allowances*. Recuperado el 19 de 06 de 2018, de Markets Insider: http://markets.businessinsider.com/commodities/co2-emissionsrechte

Mexican Federal Government. (23 de 09 de 2014). *Intended Nationally Determined Contribution.* Recuperado el 03 de 06 de 2018, de https://www.gob.mx/cms/uploads/attachment/file/162973/2015_indc_ing.pdf

Nicholas Institute for Environmental Policy Solutions. (2018). *Nicholas Institute for Environmental Policy Solutions*. Recuperado el 24 de 08 de 2018, de CAP and Trade: https://nicholasinstitute.duke.edu/focal-areas/cap-and-trade/cap-and-trade-faqs

Octaviano, C., Paltsev, S., & Costa Gurgel, A. (2016). Climate change policy in Brazil and Mexico: Results from the MIT. *Energy Economics*, Pages 600-614.

Ortega Díaz, A., & Casamadrid Gutiérrez, E. (2018). Competing actors in the climate change arena in Mexico: A network. *Journal of Environmental Management*, 239-247.

OSeMOSYS. (2018). *OSeMOSYS.* Recuperado el 06 de 06 de 2018, de http://www.osemosys.org/

Pérez-Denicia, E., Fernández-Luqueño, F., Vilariño-Ayala, D., Montaño-Zetina, L. M., & Maldonado-López, L. A. (2017). Renewable energy sources for electricity generation in Mexico: A review. *Renewable and Sustainable Energy Reviews, 78*, 597-613.

PRODESEN. (05 de 05 de 2017). *PRODESEN.* Recuperado el 29 de 06 de 2018, de Base de datos de precios de combustibles.: http://base.energia.gob.mx/prodesen/PRODESEN2017/PreciosCombustibles.xlsx

PRODESEN. (2017). *Programa de Desarrollo del Sistema Eléctrico Nacional 2017-2031.* Recuperado el 12 de 05 de 2018, de Capítulo 4.: http://base.energia.gob.mx/prodesen/PRODESEN2017/Capitulo4.xlsx

PRODESEN. (2017). *Programa Indicativo para la Instalación y Retiro de Centrales Eléctricas (PIIRCE).* Recuperado el 16 de 04 de 2018, de http://base.energia.gob.mx/prodesen/PRODESEN2017/Generacion.xlsx

PRODESEN. (2017). *Sistema Eléctrico Nacional 2017-2031.* Recuperado el 04 de 04 de 2018, de PRODESEN: http://base.energia.gob.mx/prodesen/PRODESEN2017/PRODESEN-2017-2031.pdf

Rosales, A. (2017). Contentious nationalization and the embrace of the developmental ideals: Resource nationalism in the 1970s in Ecuador. *4*(102-110).

SEGOB. (02 de 12 de 2016). *Diario Oficial de la Federación.* Recuperado el 26 de 02 de 2018, de http://www.dof.gob.mx/nota_detalle.php?codigo=5463923&fecha=02/12/2016

SEMARNAT. (28 de 10 de 2014). *Secretaria del Medio Ambiente y Recursos Naturales.* Recuperado el 27 de 02 de 2018, de http://biblioteca.semarnat.gob.mx/janium/Documentos/Ciga/agenda/DOFsr/DO3452.pdf

SEMARNAT. (02 de 2016). *SEMARNAT. Avances en materia de cambio Climático.* Recuperado el 17 de 03 de 2018, de https://www.cepal.org/sites/default/files/courses/files/04.mexico_enrique_lendo-semarnat_tallereuroclima_feb2016.pdf

SEMARNAT. (24 de 10 de 2017). *SEMARNAT. Impuesto al contenido de Carbono en Combustibles fósiles.* Recuperado el 06 de 04 de 2018, de file:///C:/Users/agustin/Downloads/iImpuesto%20al%20carbono_LEAD_241017%20(1).pdf

SEMARNAT. (03 de 03 de 2017). *SEMARNAT. Mexico Carbon Tax.* Recuperado el 05 de 04 de 2018, de https://www.thepmr.org/system/files/documents/Mexico%20Carbon%20Tax_PMR_march_2017.pdf

SEMARNAT. (2018). *México a la vanguardia en el combate y atención del Cambio Climático.* Secretaría de Medio Ambiente y Recursos Naturales.

SENER. (2016). *PRODESEN.* Recuperado el 16 de 04 de 2018, de Bases de datos de precios de combustibles.: http://base.energia.gob.mx/prodesen/PRODESEN2017/PreciosCombustibles.xlsx

SENER. (2016). *SENER.* Recuperado el 01 de 03 de 2018, de https://www.gob.mx: https://www.gob.mx/cms/uploads/attachment/file/177622/Prospectiva_de_Energ_as_Renovables_2016-2030.pdf

SENER. (31 de 08 de 2017). *Balance Nacional de Energía 2016.* Recuperado el 12 de 06 de 2018, de https://www.gob.mx/cms/uploads/attachment/file/288692/Balance_Nacional_de_Energ_a_2016__2_.pdf

SENER. (30 de 08 de 2017). *PRODESEN.* Recuperado el 30 de 05 de 2018, de Programa de Desarrollo del Sistema Eléctrico Nacional: http://base.energia.gob.mx/prodesen/PRODESEN2017/Capitulo4.xlsx

SENER. (2017). *Renewable Energy Prospective 2017-2031.* Recuperado el 11 de 11 de 2018, de Renewable Energy Prospective 2017-2031: https://www.gob.mx/cms/uploads/attachment/file/284342/Prospectiva_de_Energ_as_Renovables_2017.pdf

SENER. (2017). *Secretaría de Energía.* Recuperado el 01 de 06 de 2018, de Perspectiva del Sector Eléctrico 2017: https://www.gob.mx/cms/uploads/attachment/file/284345/Prospectiva_del_Sector_El_ctrico_2017.pdf

Stavins, R. (2001). Experience with Market-Based Environmental Policy Instruments. *Resources for the Future*, 01-58.

Taliotis, C., Rogner, H., Ressl, S., Howells, M., & Gardumi, F. (2017). Natural gas in Cyprus: The need for consolidated planning. *Energy Policy*, 197-209.

Toumi, O., Le Gallo, J., & Ben Rejeb, J. (2017). Assessment of Latin American sustainability. *Renewable and Sustainable Energy Reviews*, 878-885.

UK Government. (04 de 08 de 2017). *Greenhouse gas reporting: conversion factors 2017.* Recuperado el 05 de 05 de 2018, de Greenhouse gas reporting: conversion factors 2017: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/635632/Conversion_factors_2017_-_Condensed_set__for_most_users__v02-00.xls

UN. (2017). *Financing Solutions for Sustainable Development*. Recuperado el 23 de 03 de 2018, de Financing Solutions for Sustainable Development. Carbon Markets: http://www.undp.org/content/sdfinance/en/home/solutions/carbon-markets.html

UNFCCC. (05 de 10 de 2016). *Paris Agreement. Status of Ratification*. Recuperado el 12 de 07 de 2018, de https://unfccc.int/process/the-paris-agreement/status-of-ratification

UNFCCC. (2016). *Status of Ratification of the Kyoto Protocol*. Recuperado el 07 de 04 de 2018, de http://unfccc.int/kyoto_protocol/status_of_ratification/items/2613.php

UNFCCC. (2016). *United Nations. Climate Change*. Recuperado el 04 de 07 de 2018, de http://unfccc.int/essential_background/items/6031.php

UNFCCC. (2016). *United Nations. Climate Change*. Recuperado el 04 de 04 de 2018, de United Nations. Climate Change: http://unfccc.int/kyoto_protocol/items/3145.php

UNFCCC. (2016). *United Nations. Framework Convention on Climate Change*. Recuperado el 25 de 03 de 2018, de http://unfccc.int/timeline/

UNFCCC. (2016). *United Nations. Kyoto Protocol*. Recuperado el 25 de 03 de 2018, de United Nations. Kyoto Protocol: http://unfccc.int/kyoto_protocol/items/2830.php

Welsch, M., Deane, P., Howells, M., Ó Gallachóir, B., Rogan, F., Bazilian, M., y otros. (2014). Incorporating flexibility requirements into long-term energy system models – A case study on high levels of renewable electricity penetration in Ireland. *Applied Energy*, Pages 600-615.

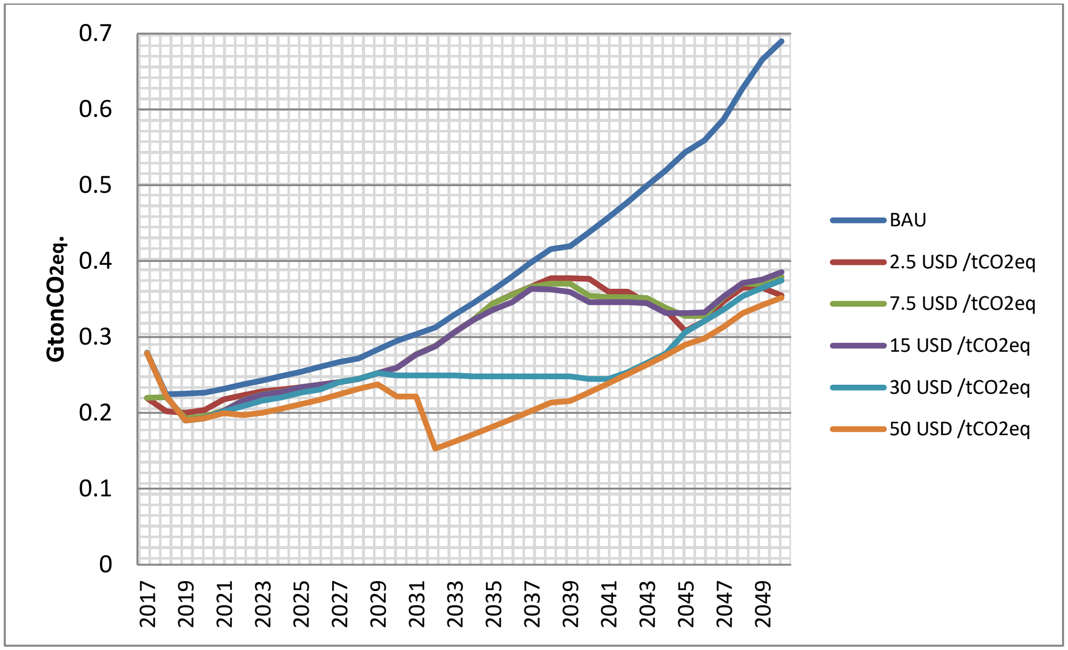
Xu, X., Xu, X., & He, P. (2016). Joint production and pricing decisions for multiple products with cap-and-trade and carbon tax regulations. *Journal of Cleaner Production*, 4093-4106.

Yamin Vázquez, P. (09 de 2013). *International Studies Association.* Recuperado el 02 de 10 de 2018, de http://web.isanet.org/Web/Conferences/FLACSO-ISA%20BuenosAires%202014/Archive/3e8cc2b9-d6bb-4293-89b1-626b6fd7fce7.pdf

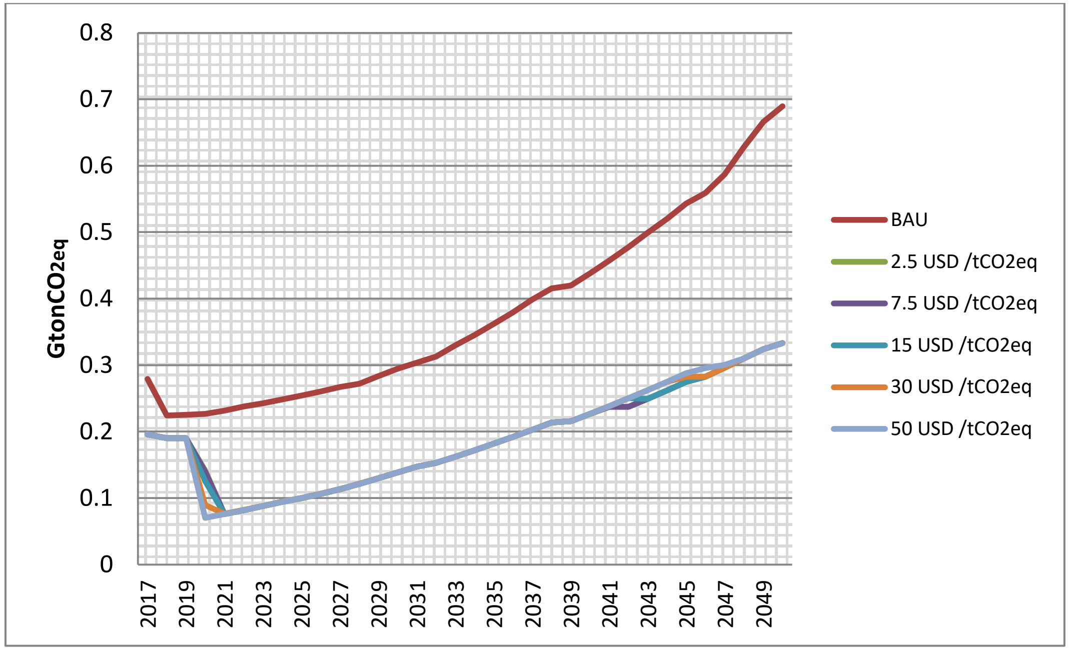
Zenón, E., & Rosellón, J. (2017). Optimal transmission planning under the Mexican new electricity market. *Energy Policy*, 349-360.

Zhang, M., Liu, Y., & Su, Y. (2017). Comparison of Carbon Emission Trading Schemes in the European Union and China. *MDPI. Climate*.

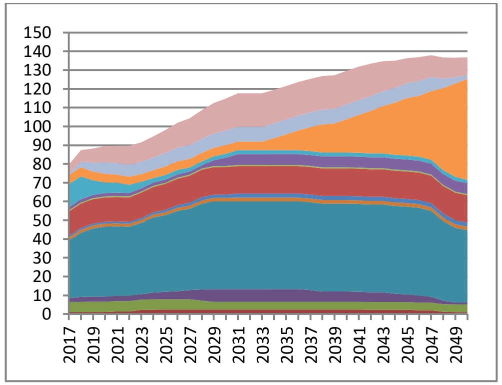
Appendix 1 (1/1). Total emissions under a 22% less emissions CAP. All the scenarios.



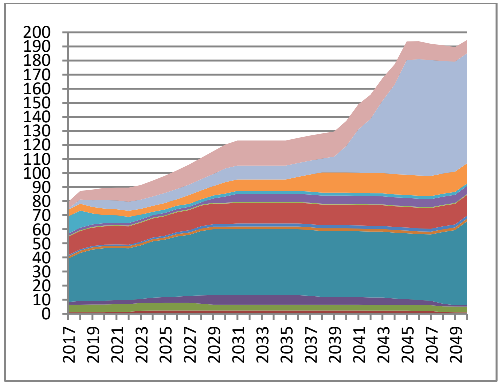
Appendix 2 (1/1). Total emissions under a 50% less emissions CAP. All the scenarios.



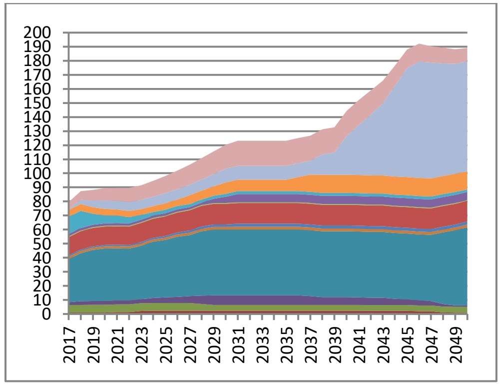
Appendix 3 (1/1). Installed Capacity (GW) from 2017 to 2050. Cap with 22% less emissions.



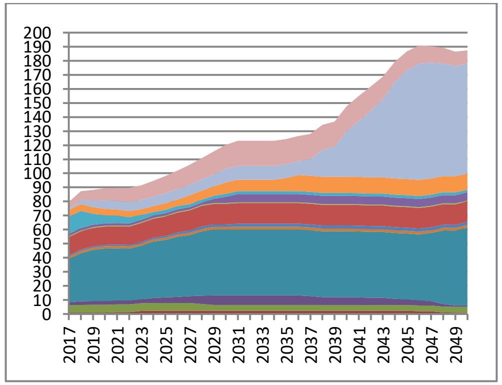
BAU



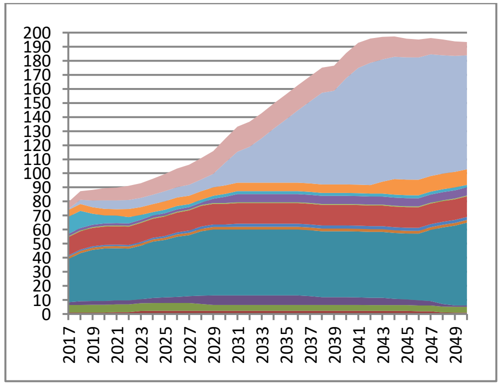
Penalty 2.5 USD/tCO$_{2eq}$



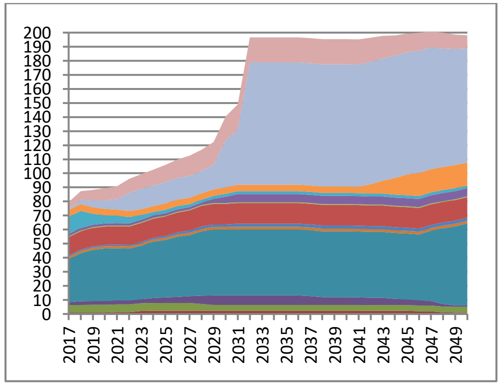
Penalty 7.5 USD/tCO$_{2eq}$



Penalty 15 USD/tCO$_{2eq}$

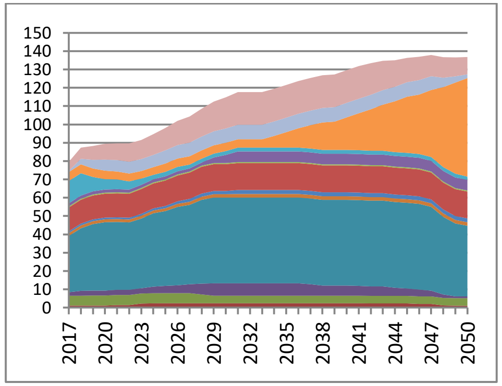


Penalty 30 USD/tCO$_{2eq}$



Penalty 50 USD/tCO2$_{eq}$

Appendix 4 (1/1). Installed Capacity (GW) from 2017 to 2050. Cap with 50% less emissions.



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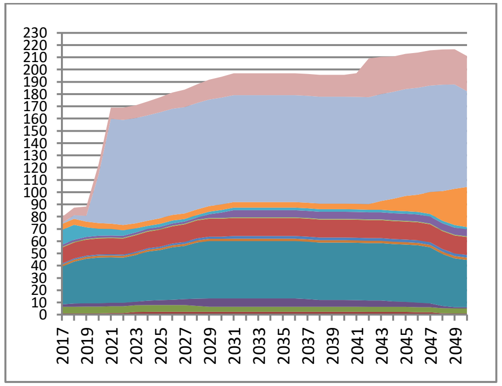
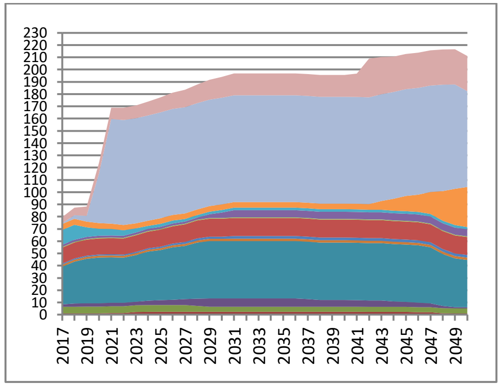
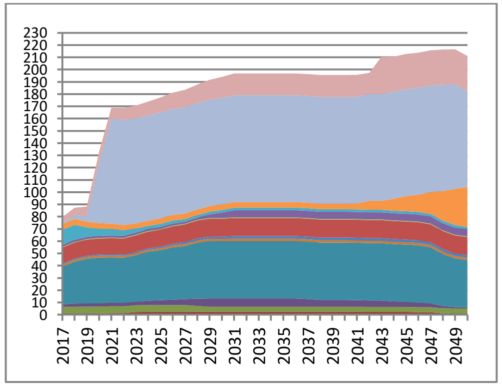


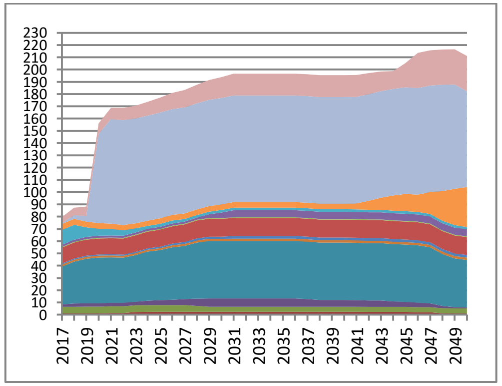
Penalty 2.5 USD/tCO$_{2eq}$



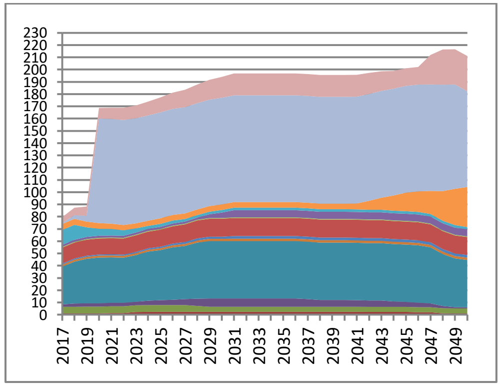
Penalty 7.5 USD/tCO$_{2eq}$



Penalty 15 USD/tCO$_{2eq}$

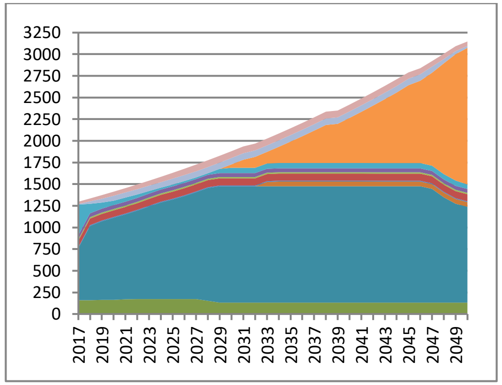


Penalty 30 USD/tCO$_{2eq}$



Penalty 50 USD/tCO2$_{eq}$

Appendix 5 (1/1). Electricity Generation (PJ) from 2017 to 2050. Cap with 22% less emissions.



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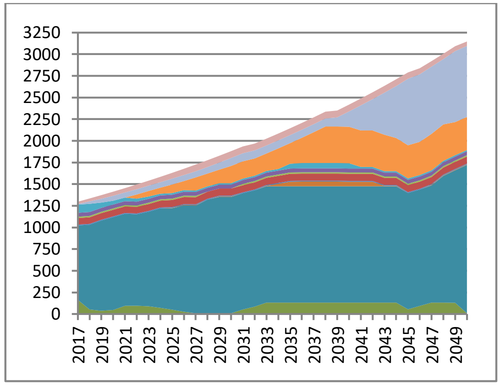
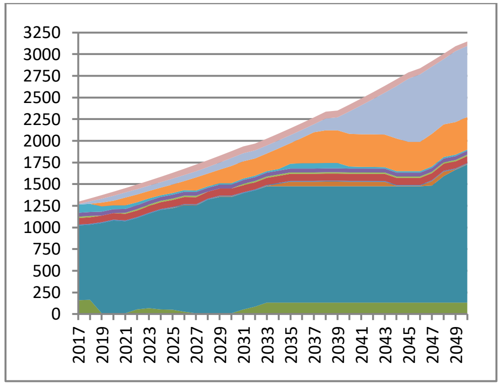
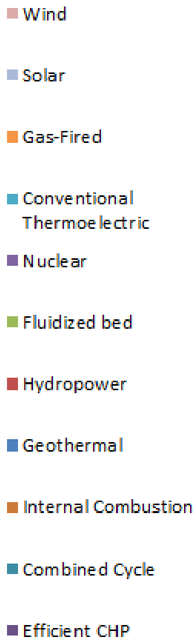
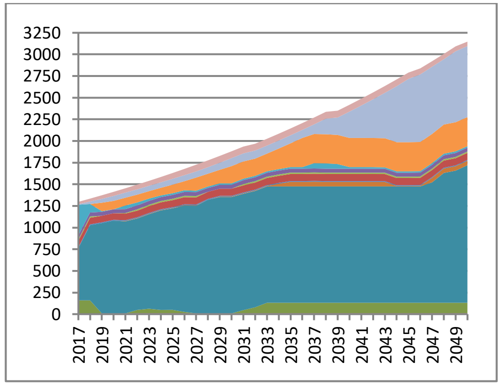


Penalty 2.5 USD/tCO_{2eq}

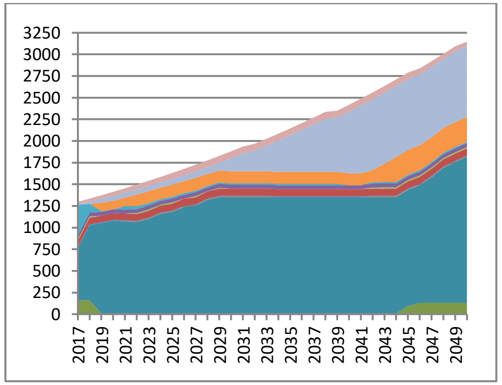


Penalty 7.5 USD/tCO_{2eq}

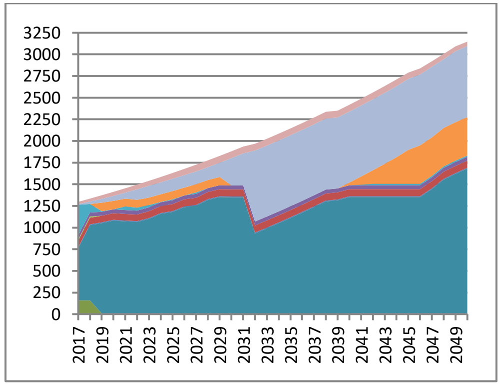




Penalty 15 USD/tCO_{2eq}

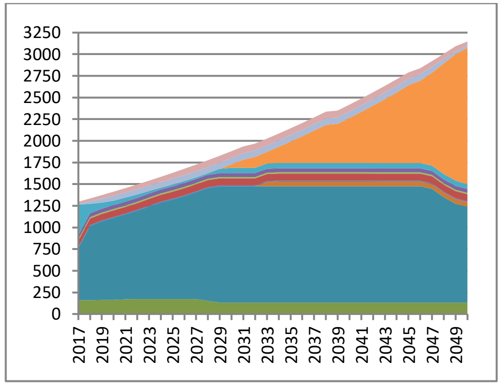


Penalty 30 USD/tCO_{2eq}



Penalty 50 USD/tCO2$_{eq}$

Appendix 6 (1/1). Electricity Generation (PJ) from 2017 to 2050. Cap with 50% less emissions.



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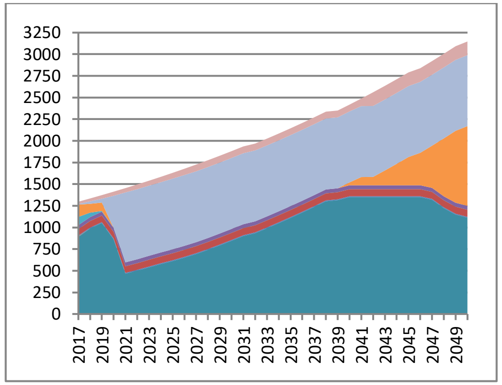
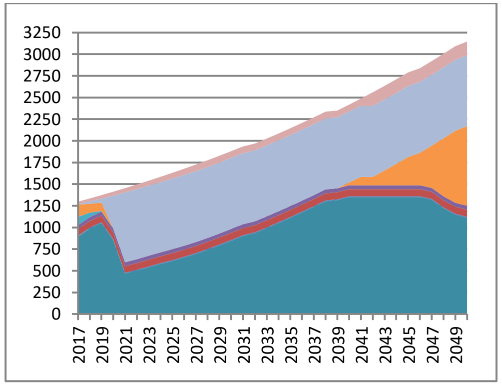
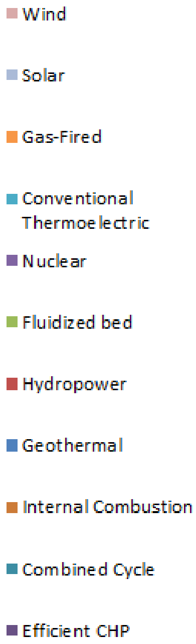
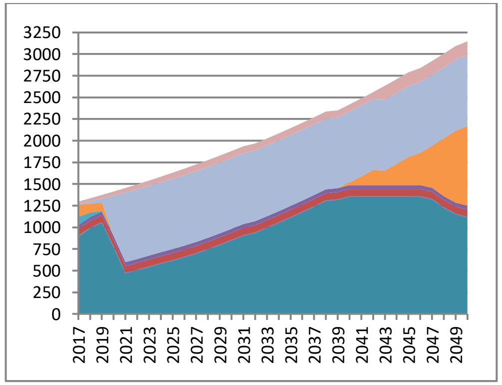


Penalty 2.5 USD/tCO$_{2eq}$

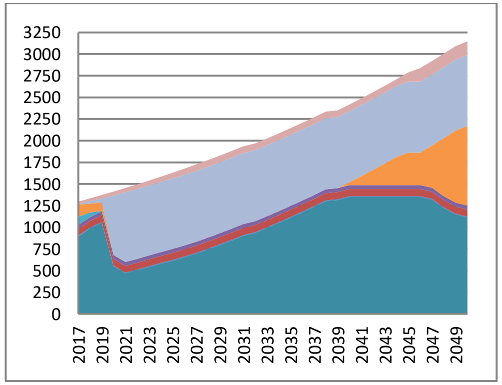


Penalty 7.5 USD/tCO$_{2eq}$

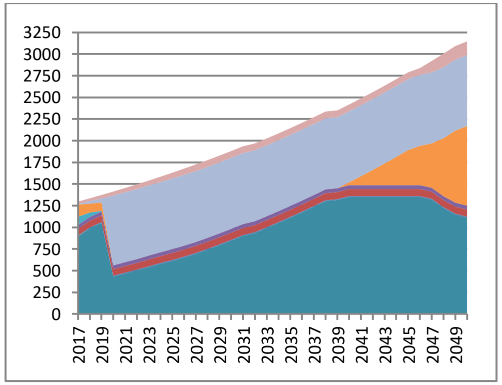




Penalty 15 USD/tCO$_{2eq}$



Penalty 30 USD/tCO$_{2eq}$



Penalty 50 USD/tCO2$_{eq}$

Appendix 7 (1/2). Capital costs (Million USD/GW).

Technology	Fuel	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
BIOEBACA	BACA	2010	2010	2010	2010	2006	2001	1997	1993	1989	1984	1980	1976	1972	1967	1963	1959	1954
BIOEBIGA	BIGA	3020	3020	3020	3020	3014	3007	3001	2994	2988	2981	2975	2969	2962	2956	2949	2943	2936
BIOECOMB	COMB	2010	2010	2010	2010	2006	2001	1997	1993	1989	1984	1980	1976	1972	1967	1963	1959	1954
BIOEGANA	GANA	2010	2010	2010	2010	2006	2001	1997	1993	1989	1984	1980	1976	1972	1967	1963	1959	1954
BIOERESO	RESO	2010	2010	2010	2010	2006	2001	1997	1993	1989	1984	1980	1976	1972	1967	1963	1959	1954
CAELCARB	CARB	1402	1402	1402	1402	1402	1402	1402	1402	1402	1402	1402	1402	1402	1402	1402	1402	1402
CHPEBACA	BACA	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010
CHPEBIGA	BIGA	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770
CHPECOMB	COMB	959	959	959	959	959	959	959	959	959	959	959	959	959	959	959	959	959
CHPEDIES	DIES	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800
CHPEGANA	GANA	780	780	780	780	780	780	780	780	780	780	780	780	780	780	780	780	780
CICOGAN2	GANA	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960
CICOGANA	GANA	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960
COINCOM2	COMB	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020
COINCOMB	COMB	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020
COINDIE2	DIES	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020
COINDIES	DIES	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020
COINGAN2	GANA	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020
COINGANA	GANA	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020
GEOTEXTR		1843	1835	1826	1818	1809	1801	1792	1784	1775	1767	1759	1750	1742	1733	1725	1716	1708
HYDRPOWR		1900	1900	1900	1900	1905	1909	1914	1918	1923	1927	1932	1936	1941	1945	1945	1945	1945
IMPOURAN	URAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LEFUCOQU	CARB	959	959	959	959	959	959	959	959	959	959	959	959	959	959	959	959	959
NUCLURAN	URAN	3920	3920	3920	3920	3920	3920	3920	3920	3920	3920	3920	3920	3920	3920	3920	3920	3920
TECOCOMB	DIES	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614
TECODIES	DIES	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614
TECOGANA	GANA	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614
TGASDIE2	DIES	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800
TGASDIES	DIES	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800
TGASGAN2	GANA	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800
TGASGANA	GANA	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800
TSOLPV01	PV01	1207	1121	1034	948	928	909	889	870	850	831	811	792	772	753	744	736	728
WINDEXTR		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WINDOFFS	OFFS	4900	4750	4600	4450	4360	4270	4180	4090	4000	3910	3820	3730	3640	3550	3520	3490	3460
WINDONSH	ONSH	1400	1388	1375	1363	1359	1355	1350	1346	1342	1338	1334	1330	1326	1322	1322	1322	1322

Appendix 7 (2/2). Capital costs (Million USD/GW).

Technology	Fuel	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
BIOEBACA	BACA	1950	1946	1942	1937	1933	1929	1924	1924	1924	1924	1924	1924	1924	1924	1924	1924	1924
BIOEBIGA	BIGA	2930	2924	2917	2911	2904	2898	2891	2891	2891	2891	2891	2891	2891	2891	2891	2891	2891
BIOECOMB	COMB	1950	1946	1942	1937	1933	1929	1924	1924	1924	1924	1924	1924	1924	1924	1924	1924	1924
BIOEGANA	GANA	1950	1946	1942	1937	1933	1929	1924	1924	1924	1924	1924	1924	1924	1924	1924	1924	1924
BIOERESO	RESO	1950	1946	1942	1937	1933	1929	1924	1924	1924	1924	1924	1924	1924	1924	1924	1924	1924
CAELCARB	CARB	1402	1402	1402	1402	1402	1402	1402	1402	1402	1402	1402	1402	1402	1402	1402	1402	1402
CHPEBACA	BACA	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010	2010
CHPEBIGA	BIGA	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770	2770
CHPECOMB	COMB	959	959	959	959	959	959	959	959	959	959	959	959	959	959	959	959	959
CHPEDIES	DIES	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800
CHPEGANA	GANA	780	780	780	780	780	780	780	780	780	780	780	780	780	780	780	780	780
CICOGAN2	GANA	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960
CICOGANA	GANA	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960
COINCOM2	COMB	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020
COINCOMB	COMB	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020
COINDIE2	DIES	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020
COINDIES	DIES	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020
COINGAN2	GANA	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020
COINGANA	GANA	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020	3020
GEOTEXTR		1699	1691	1682	1674	1666	1657	1649	1649	1649	1649	1649	1649	1649	1649	1649	1649	1649
HYDRPOWR		1945	1945	1945	1945	1945	1945	1945	1945	1945	1945	1945	1945	1945	1945	1945	1945	1945
IMPOURAN	URAN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LEFUCOQU	CARB	959	959	959	959	959	959	959	959	959	959	959	959	959	959	959	959	959
NUCLURAN	URAN	3920	3920	3920	3920	3920	3920	3920	3920	3920	3920	3920	3920	3920	3920	3920	3920	3920
TECOCOMB	DIES	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614
TECODIES	DIES	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614
TECOGANA	GANA	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614	1614
TGASDIE2	DIES	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800
TGASDIES	DIES	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800
TGASGAN2	GANA	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800
TGASGANA	GANA	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800	800
TSOLPV01	PV01	719	711	703	694	686	677	669	669	669	669	669	669	669	669	669	669	669
WINDEXTR		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WINDOFFS	OFFS	3430	3400	3370	3340	3310	3280	3250	3250	3250	3250	3250	3250	3250	3250	3250	3250	3250
WINDONSH	ONSH	1322	1322	1322	1322	1322	1322	1322	1322	1322	1322	1322	1322	1322	1322	1322	1322	1322

Appendix 8 (1/2). Fixed costs (Million USD/GW year).

Technology	Fuel	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
BIOEBACA	BACA	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	43.88	43.63
BIOEBIGA	BIGA	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.25	33.07
BIOECOMB	COMB	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	43.88	43.63
BIOEGANA	GANA	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	43.88	43.63
BIOERESO	RESO	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	43.88	43.63
CAELCARB	CARB	33.20	33.20	33.20	33.20	33.20	33.20	33.20	33.20	33.20	33.20	33.20	33.20	33.20	33.20	33.20	33.20
CHPEBACA	BACA	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12
CHPEBIGA	BIGA	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
CHPECOMB	COMB	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12
CHPEDIES	DIES	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
CHPEGANA	GANA	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69
CICOGAN2	GANA	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69
CICOGANA	GANA	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69
COINCOM2	COMB	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44
COINCOMB	COMB	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44
COINDIE2	DIES	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44
COINDIES	DIES	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44
COINGAN2	GANA	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44
COINGANA	GANA	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44
GEOTEXTR		103.37	103.37	103.37	103.37	102.22	101.07	99.92	98.77	97.62	96.47	95.33	94.18	93.03	91.88	91.88	91.88
HYDRPOWR		24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13
LEFUCOQU	CARB	79.70	79.70	79.70	79.70	79.70	79.70	79.70	79.70	79.70	79.70	79.70	79.70	79.70	79.70	79.70	79.70
NUCLURAN	URAN	99.45	99.45	99.45	99.45	99.45	99.45	99.45	99.45	99.45	99.45	99.45	99.45	99.45	99.45	99.45	99.45
TECOCOMB	DIES	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26
TECODIES	DIES	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26
TECOGANA	GANA	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26
TGASDIE2	DIES	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
TGASDIES	DIES	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
TGASGAN2	GANA	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
TGASGANA	GANA	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
TSOLPV01	PV01	10.15	9.98	9.80	9.63	9.54	9.45	9.36	9.28	9.19	9.10	9.01	8.93	8.84	8.75	8.75	8.75
WINDOFFS	OFFS	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00
WINDONSH	ONSH	37.50	37.50	37.50	37.50	37.30	37.11	36.91	36.71	36.51	36.32	36.12	35.92	35.72	35.53	35.53	35.53

Appendix 8 (2/2). Fixed costs (Million USD/GW year).

Technology	Fuel	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
BIOEBACA	BACA	43.39	43.14	42.89	42.65	42.40	42.16	41.91	41.67	41.67	41.67	41.67	41.67	41.67	41.67	41.67	41.67	41.67	41.67
BIOEBIGA	BIGA	32.88	32.70	32.51	32.33	32.14	31.95	31.77	31.58	31.58	31.58	31.58	31.58	31.58	31.58	31.58	31.58	31.58	31.58
BIOECOMB	COMB	43.39	43.14	42.89	42.65	42.40	42.16	41.91	41.67	41.67	41.67	41.67	41.67	41.67	41.67	41.67	41.67	41.67	41.67
BIOEGANA	GANA	43.39	43.14	42.89	42.65	42.40	42.16	41.91	41.67	41.67	41.67	41.67	41.67	41.67	41.67	41.67	41.67	41.67	41.67
BIOERESO	RESO	43.39	43.14	42.89	42.65	42.40	42.16	41.91	41.67	41.67	41.67	41.67	41.67	41.67	41.67	41.67	41.67	41.67	41.67
CAELCARB	CARB	33.20	33.20	33.20	33.20	33.20	33.20	33.20	33.20	33.20	33.20	33.20	33.20	33.20	33.20	33.20	33.20	33.20	33.20
CHPEBACA	BACA	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12
CHPEBIGA	BIGA	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
CHPECOMB	COMB	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12	44.12
CHPEDIES	DIES	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
CHPEGANA	GANA	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69
CICOGAN2	GANA	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69
CICOGANA	GANA	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69	15.69
COINCOM2	COMB	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44
COINCOMB	COMB	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44
COINDIE2	DIES	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44
COINDIES	DIES	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44
COINGAN2	GANA	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44
COINGANA	GANA	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44	33.44
GEOTEXTR		91.88	91.88	91.88	91.88	91.88	91.88	91.88	91.88	91.88	91.88	91.88	91.88	91.88	91.88	91.88	91.88	91.88	91.88
HYDRPOWR		24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13
LEFUCOQU	CARB	79.70	79.70	79.70	79.70	79.70	79.70	79.70	79.70	79.70	79.70	79.70	79.70	79.70	79.70	79.70	79.70	79.70	79.70
NUCLURAN	URAN	99.45	99.45	99.45	99.45	99.45	99.45	99.45	99.45	99.45	99.45	99.45	99.45	99.45	99.45	99.45	99.45	99.45	99.45
TECOCOMB	DIES	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26
TECODIES	DIES	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26
TECOGANA	GANA	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26	35.26
TGASDIE2	DIES	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
TGASDIES	DIES	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
TGASGAN2	GANA	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
TGASGANA	GANA	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
TSOLPV01	PV01	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75	8.75
WINDOFFS	OFFS	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00	140.00
WINDONSH	ONSH	35.53	35.53	35.53	35.53	35.53	35.53	35.53	35.53	35.53	35.53	35.53	35.53	35.53	35.53	35.53	35.53	35.53	35.53

Appendix 9 (1/1). Emission Factors.

Technology	Fuel	ktCO2eq/PJ
BIOEBACA	BACA	5.80
BIOEBIGA	BIGA	0.06
BIOECOMB	COMB	74.41
BIOEGANA	GANA	51.16
BIOERESO	RESO	4.36
CAELCARB	CARB	85.74
CHPEBACA	BACA	5.80
CHPEBIGA	BIGA	0.06
CHPECOMB	COMB	74.41
CHPEDIES	DIES	69.85
CHPEGANA	GANA	51.16
CICOGAN2	GANA	51.16
CICOGANA	GANA	51.16
COINCOM2	COMB	74.41
COINCOMB	COMB	74.41
COINDIE2	DIES	69.85
COINDIES	DIES	69.85

Technology	Fuel	ktCO2eq/PJ
COINGAN2	GANA	51.16
COINGANA	GANA	51.16
GEOTEXTR		0.00
HYDRPOWR		0.00
LEFUCOQU	CARB	85.74
NUCLURAN	URAN	0.00
TECOCOMB	COMB	74.41
TECODIES	DIES	69.85
TECOGANA	GANA	51.16
TGASDIE2	DIES	69.85
TGASDIES	DIES	69.85
TGASGAN2	GANA	51.16
TGASGANA	GANA	51.16
TSOLPV01	PV01	0.00
WINDOFFS	OFFS	0.00
WINDONSH	ONSH	0.00

Appendix 10 (1/1). Operational Life (Year).

Technology	Fuel	Years
BIOEBACA	BACA	25
BIOEBIGA	BIGA	25
BIOECOMB	COMB	25
BIOEGANA	GANA	25
BIOERESO	RESO	25
CAELCARB	CARB	40
CHPEBACA	BACA	20
CHPEBIGA	BIGA	20
CHPECOMB	COMB	20
CHPEDIES	DIES	20
CHPEGANA	GANA	20
CICOGAN2	GANA	30
CICOGANA	GANA	30
COINCOM2	COMB	25
COINCOMB	COMB	25
COINDIE2	DIES	25
COINDIES	DIES	25

Technology	Fuel	Years
COINGAN2	GANA	25
COINGANA	GANA	25
GEOTEXTR		30
HYDRPOWR		60
LEFUCOQU	CARB	40
NUCLURAN	URAN	60
TECOCOMB	COMB	30
TECODIES	DIES	30
TECOGANA	GANA	30
TGASDIE2	DIES	30
TGASDIES	DIES	30
TGASGAN2	GANA	30
TGASGANA	GANA	30
TSOLPV01	PV01	30
WINDOFFS	OFFS	25
WINDONSH	ONSH	25

Appendix 11 (1/2). Variable Costs (Million USD/PJ).

Technology	Fuel	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2026	2027	2028	2029	2030	2031
BIOEBACA	BACA	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
BIOEBIGA	BIGA	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
BIOECOMB	COMB	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18
BIOEGANA	GANA	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
BIOERESO	RESO	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
CAELCARB	CARB	0.67	0.74	0.78	0.82	0.85	0.87	0.87	0.87	0.88	0.89	0.90	0.89	0.90	0.90	0.91	0.91	0.92
CHPEBACA	BACA	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
CHPEBIGA	BIGA	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
CHPECOMB	COMB	0.56	0.66	0.73	0.80	0.85	0.88	0.91	0.93	0.95	0.98	1.01	0.98	1.01	1.03	1.05	1.08	1.11
CHPEDIES	DIES	0.31	0.33	0.35	0.38	0.39	0.40	0.41	0.42	0.43	0.43	0.44	0.43	0.44	0.45	0.46	0.46	0.47
CHPEGANA	GANA	0.38	0.41	0.43	0.46	0.48	0.51	0.52	0.53	0.54	0.56	0.57	0.56	0.57	0.57	0.57	0.57	0.57
CICOGAN2	GANA	0.91	0.97	1.03	1.09	1.15	1.21	1.24	1.26	1.29	1.31	1.34	1.31	1.34	1.35	1.35	1.35	1.35
CICOGANA	GANA	0.91	0.97	1.03	1.09	1.15	1.21	1.24	1.26	1.29	1.31	1.34	1.31	1.34	1.35	1.35	1.35	1.35
COINCOM2	COMB	1.41	1.67	1.86	2.03	2.16	2.24	2.32	2.35	2.43	2.50	2.58	2.50	2.58	2.63	2.69	2.74	2.82
COINCOMB	COMB	1.41	1.67	1.86	2.03	2.16	2.24	2.32	2.35	2.43	2.50	2.58	2.50	2.58	2.63	2.69	2.74	2.82
COINDIE2	DIES	1.41	1.52	1.63	1.75	1.83	1.87	1.91	1.94	1.97	2.00	2.05	2.00	2.05	2.08	2.13	2.15	2.19
COINDIES	DIES	1.41	1.52	1.63	1.75	1.83	1.87	1.91	1.94	1.97	2.00	2.05	2.00	2.05	2.08	2.13	2.15	2.19
COINGAN2	GANA	1.41	1.52	1.60	1.70	1.79	1.87	1.94	1.97	2.00	2.05	2.10	2.05	2.10	2.10	2.10	2.10	2.11
COINGANA	GANA	1.41	1.52	1.60	1.70	1.79	1.87	1.94	1.97	2.00	2.05	2.10	2.05	2.10	2.10	2.10	2.10	2.11
GEOTEXTR		0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
HYDRPOWR		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LEFUCOQU	CARB	0.68	0.76	0.80	0.84	0.87	0.88	0.89	0.89	0.90	0.91	0.92	0.91	0.92	0.92	0.93	0.93	0.94
NUCLURAN	URAN	0.66	0.66	0.66	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.69	0.67	0.69	0.69	0.69	0.69	0.71
TECOCOMB	DIES	0.83	0.98	1.09	1.20	1.27	1.32	1.36	1.39	1.43	1.48	1.52	1.48	1.52	1.55	1.58	1.61	1.66
TECODIES	DIES	0.83	0.90	0.96	1.03	1.07	1.10	1.13	1.14	1.16	1.18	1.21	1.18	1.21	1.23	1.26	1.27	1.29
TECOGANA	GANA	0.83	0.89	0.95	1.00	1.05	1.10	1.14	1.16	1.18	1.21	1.23	1.21	1.23	1.24	1.24	1.24	1.24
TGASDIE2	DIES	1.31	1.41	1.51	1.61	1.68	1.73	1.76	1.78	1.82	1.85	1.89	1.85	1.89	1.93	1.97	1.99	2.03
TGASDIES	DIES	1.31	1.41	1.51	1.61	1.68	1.73	1.76	1.78	1.82	1.85	1.89	1.85	1.89	1.93	1.97	1.99	2.03
TGASGAN2	GANA	1.31	1.40	1.48	1.57	1.65	1.73	1.78	1.82	1.85	1.89	1.93	1.89	1.93	1.93	1.94	1.94	1.95
TGASGANA	GANA	1.31	1.40	1.48	1.57	1.65	1.73	1.78	1.82	1.85	1.89	1.93	1.89	1.93	1.93	1.94	1.94	1.95
TSOLPV01	PV01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WINDOFFS	OFFS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WINDONSH	ONSH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 11 (2/2). Variable Costs (Million USD/PJ).

Technology	Fuel	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
BIOEBACA	BACA	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
BIOEBIGA	BIGA	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88
BIOECOMB	COMB	1.22	1.27	1.31	1.36	1.41	1.46	1.51	1.57	1.62	1.68	1.74	1.80	1.87	1.94	2.01	2.08	2.15	2.23	2.31
BIOEGANA	GANA	1.13	1.16	1.20	1.24	1.29	1.33	1.38	1.42	1.47	1.52	1.57	1.63	1.68	1.74	1.80	1.86	1.92	1.99	2.06
BIOERESO	RESO	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
CAELCARB	CARB	0.93	0.94	0.95	0.95	0.96	0.97	0.98	0.98	0.99	1.00	1.01	1.02	1.02	1.03	1.04	1.05	1.06	1.07	1.07
CHPEBACA	BACA	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39	0.39
CHPEBIGA	BIGA	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
CHPECOMB	COMB	1.15	1.19	1.23	1.28	1.32	1.37	1.42	1.47	1.52	1.58	1.63	1.69	1.75	1.82	1.88	1.95	2.02	2.09	2.17
CHPEDIES	DIES	0.49	0.50	0.51	0.52	0.54	0.55	0.56	0.58	0.59	0.61	0.62	0.64	0.65	0.67	0.69	0.70	0.72	0.74	0.76
CHPEGANA	GANA	0.59	0.61	0.63	0.65	0.68	0.70	0.72	0.75	0.77	0.77	0.80	0.83	0.85	0.88	0.91	0.94	0.98	1.01	1.04
CICOGAN2	GANA	1.39	1.44	1.49	1.55	1.60	1.65	1.70	1.76	1.82	1.89	1.95	2.02	2.08	2.15	2.23	2.30	2.39	2.47	2.55
CICOGANA	GANA	1.39	1.44	1.49	1.55	1.60	1.65	1.70	1.76	1.82	1.89	1.95	2.02	2.08	2.15	2.23	2.30	2.39	2.47	2.55
COINCOM2	COMB	2.91	3.03	3.14	3.25	3.36	3.49	3.62	3.75	3.87	4.02	4.16	4.31	4.47	4.63	4.79	4.96	5.14	5.33	5.52
COINCOMB	COMB	2.91	3.03	3.14	3.25	3.36	3.49	3.62	3.75	3.87	4.02	4.16	4.31	4.47	4.63	4.79	4.96	5.14	5.33	5.52
COINDIE2	DIES	2.24	2.29	2.35	2.40	2.47	2.53	2.59	2.66	2.72	2.79	2.87	2.93	3.01	3.09	3.15	3.23	3.31	3.41	3.49
COINDIES	DIES	2.24	2.29	2.35	2.40	2.47	2.53	2.59	2.66	2.72	2.79	2.87	2.93	3.01	3.09	3.15	3.23	3.31	3.41	3.49
COINGAN2	GANA	2.18	2.26	2.34	2.40	2.50	2.58	2.66	2.75	2.85	2.95	3.04	3.15	3.25	3.36	3.47	3.60	3.71	3.84	3.97
COINGANA	GANA	2.18	2.26	2.34	2.40	2.50	2.58	2.66	2.75	2.85	2.95	3.04	3.15	3.25	3.36	3.47	3.60	3.71	3.84	3.97
GEOTEXTR		0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
HYDRPOWR		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
LEFUCOQU	CARB	0.95	0.95	0.96	0.97	0.98	0.98	0.99	1.00	1.01	1.02	1.02	1.03	1.04	1.05	1.06	1.07	1.07	1.08	1.09
NUCLURAN	URAN	0.72	0.74	0.76	0.78	0.80	0.82	0.84	0.86	0.88	0.90	0.93	0.95	0.97	1.00	1.02	1.05	1.07	1.10	1.13
TECOCOMB	DIES	1.72	1.78	1.85	1.91	1.98	2.05	2.13	2.20	2.28	2.37	2.45	2.54	2.63	2.73	2.82	2.92	3.03	3.14	3.25
TECODIES	DIES	1.33	1.36	1.39	1.43	1.46	1.50	1.54	1.58	1.62	1.66	1.70	1.74	1.78	1.83	1.87	1.92	1.97	2.02	2.07
TECOGANA	GANA	1.28	1.33	1.37	1.42	1.47	1.52	1.57	1.62	1.68	1.73	1.79	1.85	1.92	1.98	2.05	2.12	2.19	2.27	2.34
TGASDIE2	DIES	2.08	2.13	2.18	2.24	2.29	2.35	2.41	2.47	2.53	2.59	2.66	2.73	2.79	2.86	2.93	3.01	3.08	3.16	3.24
TGASDIES	DIES	2.08	2.13	2.18	2.24	2.29	2.35	2.41	2.47	2.53	2.59	2.66	2.73	2.79	2.86	2.93	3.01	3.08	3.16	3.24
TGASGAN2	GANA	2.01	2.08	2.15	2.22	2.30	2.38	2.46	2.54	2.63	2.72	2.81	2.91	3.00	3.11	3.21	3.32	3.43	3.55	3.67
TGASGANA	GANA	2.01	2.08	2.15	2.22	2.30	2.38	2.46	2.54	2.63	2.72	2.81	2.91	3.00	3.11	3.21	3.32	3.43	3.55	3.67
TSOLPV01	PV01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WINDOFFS	OFFS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WINDONSH	ONSH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 12 (1/1). Input Activity Ratio.

Technology	Fuel	Efficiency (%)	Ratio
BIOEBACA	BACA	35%	2.85
BIOEBIGA	BIGA	30%	3.33
BIOECOMB	COMB	32%	3.13
BIOEGANA	GANA	40%	2.50
BIOERESO	RESO	28%	3.57
CAELCARB	CARB	35%	2.85
CHPEBACA	BACA	45%	2.20
CHPEBIGA	BIGA	35%	2.85
CHPECOMB	COMB	50%	2.00
CHPEDIES	DIES	50%	2.00
CHPEGANA	GANA	50%	2.00
CICOGAN2	GANA	45%	2.22
CICOGANA	GANA	45%	2.22
COINCOM2	COMB	30%	3.33
COINCOMB	COMB	30%	3.33
COINDIE2	DIES	32%	3.13
COINDIES	DIES	32%	3.13

Technology	Fuel	Efficiency (%)	Ratio
COINGAN2	GANA	28%	3.60
COINGANA	GANA	28%	3.60
GEOTEXTR		23%	4.34
HYDRPOWR		100%	1.00
LEFUCOQU	CARB	45%	2.22
NUCLURAN	URAN	35%	2.85
TECOCOMB	COMB	24%	4.25
TECODIES	DIES	24%	4.25
TECOGANA	GANA	30%	3.33
TGASDIE2	DIES	34%	2.98
TGASDIES	DIES	34%	2.98
TGASGAN2	GANA	45%	2.22
TGASGANA	GANA	45%	2.22
TSOLPV01	PV01	100%	1.00
WINDOFFS	OFFS	100%	1.00
WINDONSH	ONSH	100%	1.00

Appendix 13 (1/1). Total annual Minimum Capacity Investment (GW).

Technology	Fuel	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031
BIOEBACA	BACA	0.02	0.00	0.00	0.00	0.10	0.00	0.26	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00
BIOEBIGA	BIGA	0.01	0.00	0.00	0.00	0.04	0.00	0.10	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BIOECOMB	COMB	0.01	0.00	0.00	0.00	0.04	0.00	0.10	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BIOEGANA	GANA	0.01	0.00	0.00	0.00	0.04	0.00	0.10	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BIOERESO	RESO	0.02	0.00	0.00	0.00	0.10	0.00	0.26	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00
CAELCARB	CARB	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CHPEBACA	BACA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CHPEBIGA	BIGA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CHPECOMB	COMB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CHPEDIES	DIES	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CHPEGANA	GANA	0.50	0.75	0.00	0.00	0.15	0.00	0.00	0.75	0.40	0.31	0.58	1.04	0.88	0.00	0.00
CICOGAN2	GANA	0.54	1.77	1.34	0.65	0.08	0.00	0.64	1.06	0.40	1.02	0.28	1.52	0.56	0.00	0.00
CICOGANA	GANA	1.05	3.40	2.58	1.24	0.15	0.00	1.23	2.03	0.77	1.96	0.54	2.92	1.07	0.00	0.00
COINCOM2	COMB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
COINCOMB	COMB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01
COINDIE2	DIES	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.01	0.03	0.00	0.03
COINDIES	DIES	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.04	0.10	0.00	0.10
COINGAN2	GANA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01
COINGANA	GANA	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01
GEOTEXTR		0.03	0.03	0.00	0.00	0.03	0.05	0.03	0.12	0.11	0.13	0.23	0.08	0.03	0.03	0.42
HYDRPOWR		0.02	0.03	0.00	0.00	0.03	0.00	0.52	0.00	0.33	0.19	0.23	0.35	0.00	0.00	0.00
LEFUCOQU	CARB	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NUCLURAN	URAN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.36	1.36	1.36
TECOCOMB	DIES	0.00	0.00	0.00	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TECODIES	DIES	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TECOGANA	GANA	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TGASDIE2	DIES	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
TGASDIES	DIES	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.03	0.10	0.00	0.00	0.00	0.00	0.00	0.00
TGASGAN2	GANA	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.07	0.00	0.00	0.00	0.00	0.00	0.00
TGASGANA	GANA	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.08	0.24	0.00	0.00	0.00	0.00	0.00	0.00
TSOLPV01	PV01	0.39	2.36	1.73	1.33	0.21	0.16	0.13	0.12	0.54	0.12	0.10	0.11	0.10	0.17	0.10
WINDOFFS	OFFS	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WINDONSH	ONSH	0.59	1.18	1.45	1.09	0.45	0.94	0.36	0.91	0.89	1.03	1.01	0.94	1.02	0.79	0.85

Appendix 14 (1/2). Residual Capacity (GW).

Technology	Fuel	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
BIOEBACA	BACA	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
BIOEBIGA	BIGA	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
BIOECOMB	COMB	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
BIOEGANA	GANA	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
BIOERESO	RESO	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
CAELCARB	CARB	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	5.38	4.68	3.98	3.98	3.98	3.98	3.98
CHPEBACA	BACA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CHPEBIGA	BIGA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CHPECOMB	COMB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CHPEDIES	DIES	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CHPEGANA	GANA	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44
CICOGAN2	GANA	15.42	15.42	15.23	15.11	14.87	14.75	14.75	14.75	14.75	14.75	14.75	14.48	14.48	14.48	14.48	14.48	14.48
CICOGANA	GANA	14.24	14.24	14.06	13.95	13.73	13.62	13.62	13.62	13.62	13.62	13.62	13.36	13.36	13.36	13.36	13.36	13.36
COINCOM2	COMB	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
COINCOMB	COMB	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
COINDIE2	DIES	0.38	0.38	0.37	0.37	0.37	0.37	0.37	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
COINDIES	DIES	0.96	0.96	0.95	0.95	0.95	0.94	0.94	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
COINGAN2	GANA	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
COINGANA	GANA	0.10	0.10	0.10	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
GEOTEXTR		0.92	0.92	0.90	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
HYDRPOWR		12.99	12.99	12.99	12.99	12.99	12.99	12.99	12.99	12.99	12.99	12.99	12.99	12.99	12.99	12.99	12.99	12.99
LEFUCOQU	CARB	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
NUCLURAN	URAN	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71
TECOCOMB	COMB	8.45	8.45	5.43	3.68	3.46	2.85	2.12	1.45	1.45	1.45	1.22	1.22	1.22	1.22	1.22	1.22	1.22
TECODIES	DIES	0.50	0.50	0.32	0.22	0.20	0.17	0.12	0.09	0.09	0.09	0.07	0.07	0.07	0.07	0.07	0.07	0.07
TECOGANA	GANA	3.23	3.23	2.08	1.41	1.32	1.09	0.81	0.56	0.56	0.56	0.47	0.47	0.47	0.47	0.47	0.47	0.47
TGASDIE2	DIES	0.19	0.19	0.19	0.19	0.17	0.17	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
TGASDIES	DIES	1.20	1.20	1.14	1.14	1.06	1.04	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
TGASGAN2	GANA	0.94	0.94	0.90	0.90	0.83	0.81	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77
TGASGANA	GANA	2.53	2.53	2.41	2.41	2.24	2.18	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08
TSOLPV01	PV01	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23
WINDOFFS	OFFS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WINDONSH	ONSH	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35

Appendix 14 (2/2). Residual Capacity (GW).

Technology	Fuel	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
BIOEBACA	BACA	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
BIOEBIGA	BIGA	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
BIOECOMB	COMB	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
BIOEGANA	GANA	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
BIOERESO	RESO	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
CAELCARB	CARB	3.98	3.98	3.98	3.98	3.98	3.98	3.98	3.98	3.98	3.98	3.98	3.98	3.98	3.98	3.98	3.98	3.98
CHPEBACA	BACA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CHPEBIGA	BIGA	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CHPECOMB	COMB	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CHPEDIES	DIES	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
CHPEGANA	GANA	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.44	1.22	1.22	1.22	1.22	1.22	1.22	1.00	1.00	1.00
CICOGAN2	GANA	14.48	14.48	14.48	14.48	14.48	14.48	14.48	14.48	14.48	14.48	14.48	14.48	14.48	14.48	14.48	14.48	14.48
CICOGANA	GANA	13.36	13.36	13.36	13.36	13.36	13.36	13.36	13.36	13.36	13.36	13.36	13.36	13.36	13.36	13.36	13.36	13.36
COINCOM2	COMB	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
COINCOMB	COMB	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
COINDIE2	DIES	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36	0.36
COINDIES	DIES	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
COINGAN2	GANA	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
COINGANA	GANA	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
GEOTEXTR		0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
HYDRPOWR		12.99	12.99	12.99	12.99	12.99	12.99	12.99	12.99	12.99	12.99	12.99	12.99	12.99	12.99	12.99	12.99	12.99
LEFUCOQU	CARB	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58	0.58
NUCLURAN	URAN	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71	1.71
TECOCOMB	COMB	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22	1.22
TECODIES	DIES	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
TECOGANA	GANA	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
TGASDIE2	DIES	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
TGASDIES	DIES	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
TGASGAN2	GANA	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77
TGASGANA	GANA	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08	2.08
TSOLPV01	PV01	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.23	0.22	0.21	0.20
WINDOFFS	OFFS	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
WINDONSH	ONSH	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.35	4.30	4.20	4.10	4.00	3.80	3.80	3.80	3.80

Appendix 15 (1/2). Availability Factor

Technology	Fuel	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
BIOEBACA	BACA	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
BIOEBIGA	BIGA	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
BIOECOMB	COMB	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
BIOEGANA	GANA	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
BIOERESO	RESO	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
CAELCARB	CARB	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
CHPEBACA	BACA	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
CHPEBIGA	BIGA	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
CHPECOMB	COMB	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
CHPEDIES	DIES	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
CHPEGANA	GANA	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
CICOGAN2	GANA	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91
CICOGANA	GANA	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91
COINCOM2	COMB	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
COINCOMB	COMB	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
COINDIE2	DIES	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
COINDIES	DIES	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
COINGAN2	GANA	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
COINGANA	GANA	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
GEOTEXTR		0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
HYDRPOWR		0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
LEFUCOQU	CARB	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
NUCLURAN	URAN	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
TECOCOMB	COMB	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
TECODIES	DIES	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
TECOGANA	GANA	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
TGASDIE2	DIES	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
TGASDIES	DIES	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
TGASGAN2	GANA	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
TGASGANA	GANA	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
TSOLPV01	PV01	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
WINDOFFS	OFFS	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
WINDONSH	ONSH	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60

Appendix 15 (2/2). Availability Factor.

Technology	Fuel	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
BIOEBACA	BACA	0.7	0.7	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
BIOEBIGA	BIGA	0.7	0.7	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
BIOECOMB	COMB	0.7	0.7	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
BIOEGANA	GANA	0.7	0.7	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
BIOERESO	RESO	0.7	0.7	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
CAELCARB	CARB	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
CHPEBACA	BACA	0.7	0.7	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
CHPEBIGA	BIGA	0.7	0.7	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
CHPECOMB	COMB	0.7	0.7	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
CHPEDIES	DIES	0.7	0.7	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
CHPEGANA	GANA	0.7	0.7	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70
CICOGAN2	GANA	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91
CICOGANA	GANA	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91
COINCOM2	COMB	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
COINCOMB	COMB	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
COINDIE2	DIES	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
COINDIES	DIES	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
COINGAN2	GANA	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
COINGANA	GANA	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92
GEOTEXTR		0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87	0.87
HYDRPOWR		0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37
LEFUCOQU	CARB	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
NUCLURAN	URAN	0.9	0.9	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
TECOCOMB	COMB	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
TECODIES	DIES	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
TECOGANA	GANA	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
TGASDIE2	DIES	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
TGASDIES	DIES	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
TGASGAN2	GANA	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
TGASGANA	GANA	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93	0.93
TSOLPV01	PV01	0.5	0.5	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
WINDOFFS	OFFS	0.6	0.6	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
WINDONSH	ONSH	0.6	0.6	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60